INTERNATIONAL LIBRARY OF TECHNOLOGY

A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

HEAT
COMBUSTION AND FUELS
PRINCIPLES OF THE GAS ENGINE
AUTOMOBILE AND MARINE ENGINES
STATIONARY GAS ENGINES
GAS-ENGINE DETAILS
GAS-ENGINE LUBRICATION AND BEARINGS

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the

indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one select the proper formula, method, or process and in teaching him how and when it should be used.

This volume may be divided into the following sections: Heat, combustion and fuels, principles of the gas engine, automobile engines, marine engines, stationary gas engines, gas-engine details, and gas-engine lubrication and bearings. In the first section, the nature, properties, and effects of heat on gases and the relation between heat and work are considered; in the second section, the various gas-engine fuels are described, and their composition and heat value given; the third subject covers the principles involved in the performance of work by the gas engine. In the three succeeding sections, the construction of the principal types of automobile, marine, and stationary engines in general use is clearly explained. In the next section are described many of the various forms of details not previously mentioned; while in the last section, the subjects of lubrication and the construction and care of bearings are especially considered. The information here given will be found of the utmost practical value to the operator of any type of internal-combustion engine.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number, it is preceded by the printer's section mark (§). Consequently, a reference such as §16, page 26, will be readily found by looking along the inside edges of the headlines until §16 is found, and then through §16 until page 26 is found.

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HEAT

NATURE, PROPERTIES, AND EFFECTS OF HEAT

NATURE AND SOURCES OF HEAT

MODERN THEORY OF HEAT

1. Molecular Motion.—All bodies are supposed to be made up of a large number of very small parts or particles, called **molecules**, which are too small to be seen, even with the aid of the most powerful microscopes. These molecules vibrate to and fro, and, since each molecule has some weight, though very little, it possesses a certain amount of energy due to its motion. According to the modern theory, **heat** is the energy that a body possesses, due to the continual vibration of its molecules; that is, heat is the energy of molecular motion.

2. Path of Molecular Motion.—The molecules of a solid body are supposed to move with comparative slowness in fixed paths, and these paths are supposed not to change so long as the body remains in the solid state. This is due to the fact that in a solid the molecules are close together and attract one another very strongly. If the solid is heated until it melts, thus becoming a liquid, the molecules vibrate more rapidly, and no longer have definite paths of motion, but are free to move in and out among one another. When a liquid is heated, the vibratory motion increases until finally

the attractive force that holds the body together is overcome, and the molecules pass off into space. The substance is then known as a vapor or gas. The molecules, therefore, of a gas vibrate much more rapidly than the molecules of a solid or a liquid body. Furthermore, the molecules of a gaseous body have no fixed paths of motion. Consequently, when one molecule strikes another, it rebounds and keeps moving in the direction of the rebound until it strikes other molecules, thus causing the gas to expand indefinitely unless confined in a vessel under some pressure. Hence, gases are said to be perfectly expansible and perfectly elastic.

SOURCES OF HEAT

3. Heat may be derived from three sources, known as *physical*, *chemical*, and *mechanical sources*. The earth and the sun are physical sources of heat; the burning of wood, oil, or coal is an example of a chemical source of heat, since burning is a chemical action; and the rubbing together of two pieces of wood until they become warm by friction and the hammering of a piece of iron until it becomes hot, are examples of mechanical sources of heat.

CHARACTERISTIC PROPERTIES OF HEAT

TEMPERATURE

4. Definition.—The term **temperature** is used to indicate how hot or how cold a body is; that is, to indicate the velocity of the vibration of the molecules of a body. A body having a high temperature is said to be hot; a body having a low temperature is said to be cold. When a body, as, for example, an iron bar, receives heat from any source, the vibrations of its molecules become more rapid and its temperature rises; on the other hand, when a body loses heat, the vibrations of its molecules become less rapid and its temperature falls.

The temperature is *not* a measure of the *quantity* of heat a body possesses. *Temperature* may be considered to be a measure of the velocity with which the molecules of a body vibrate to and fro, while the *quantity of heat* may be considered to be the total energy of the molecules composing the body. A small iron rod may be heated to whiteness and yet possess a very small quantity of heat. Its temperature is very high, but this simply indicates that the molecules of the rod are vibrating with an extremely high velocity. An iron ball 1 foot in diameter and an iron ball 1 inch in diameter may have exactly the same *temperature*, but the larger ball will have by far the greater quantity of heat.

5. Sensible Heat.—The simplest way by which heat is recognized is by the sense of touch. If a particular object contains a large amount of heat, it feels hot; and between two objects made of the same material, the sense of touch is an approximate guide to their relative temperatures. On the other hand, between two objects made of different materials, as, for example, iron and cloth, the sense of touch may reveal nothing at all concerning their relative temperatures. The reason is that the sense of touch indicates not the temperature directly, but rather the rapidity with which heat is transferred from the object to the hand, or is abstracted from the hand if the object is colder than the hand. The heat that thus manifests itself is called **sensible heat**, because any change of the same body from any state to a hotter or colder state is indicated at once by the sense of feeling, or with the aid of instruments called *thermometers*. The more sensible heat a body possesses, the hotter it is; the more sensible heat that is taken away from it, the colder it is.

6. Measurement of Temperature.—As just stated, temperature is measured by means of an instrument called a **thermometer**, one type of which is shown in Fig. 1. It consists of a glass tube, closed at both ends and having a bulb at the lower end. The bulb and the lower end of the tube are filled with mercury, which, on being heated or cooled, expands or contracts in proportion to the change of

temperature. This expansion or contraction causes the top of the mercury column to rise or fall; and, since equal changes of temperature make the mercury column rise or fall equal distances, the graduations on the scale are made equal throughout.

In Fig. 1 is shown a **combination thermometer**, that is, one that has two scales. The scale on the left, marked *F*, forms, in combination with the glass tube, a *Fahrenheit thermometer* (so named after its inventor), which is the one commonly used; the scale on the right, marked *C*, forms, in combination with the glass tube, a *centigrade thermometer*. The centigrade thermometer is used by scientists throughout the world, because the graduations are better adapted for performing calculations.

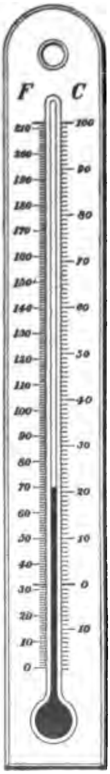

Fig. 1

7. Graduating a Thermometer.—The graduations on the scale of a thermometer are obtained as follows: The thermometer is first placed in melting ice, and the point to which the mercury column falls is marked and called the *freezing point;* the thermometer is then placed in steam that is escaping from an open vessel, and the point to which the mercury rises in the tube is marked and called the *boiling point*. These are two fixed points; that is, the mercury column will always register these same points when the thermometer is placed in broken ice or in steam, under the conditions explained above.

8. The **freezing point** marks the temperature at which, under atmospheric pressure, water freezes and forms ice, or at which ice melts and forms water, since water freezes and ice melts at exactly the same temperature, as heat is abstracted or added.

The **boiling point** marks the temperature at which water boils and forms steam under atmospheric pressure.

Having fixed these two points, the distance between them is divided into equal parts, the number of divisions depending

on whether the scale is for a Fahrenheit or for a centigrade thermometer.

9. Fahrenheit Thermometer.—The **Fahrenheit thermometer** is made by dividing the distance on the scale between the freezing and boiling points into 180 equal divisions, called *degrees*. The freezing point is marked 32, and the boiling point 212; 32 divisions are marked off from the freezing point downwards, and the lowest one is marked 0; this is called the *zero point* of the scale. The graduations may be extended above the boiling point, or below the zero point, as desired.

Instead of writing the word *degrees* after each reading of temperature it is customary to represent it by a symbol—a small circle placed above and to the right of the figures. Also, the word *Fahrenheit* is usually represented by the letter F. Thus, 32° F. means the same as though it were written "32 degrees Fahrenheit," and 8° F. means the same as "8 degrees Fahrenheit." In this thermometer, there are 212 divisions, or degrees, between the zero point and the boiling point.

10. Centigrade Thermometer.—In the **centigrade thermometer**, the freezing point is marked 0 and the boiling point 100, the distance between the two being divided into 100 equal divisions. As in the Fahrenheit scale, the divisions may be carried above the boiling point and below the zero point. The word *centigrade* is usually abbreviated and written C., as, for example, 10° C., 28° C., etc.

11. Thermometer Readings.—Beginning with 0°, the divisions on both the Fahrenheit and the centigrade scales are numbered 1, 2, 3, 4, etc., both above and below the zero point. Therefore, in giving the lower readings of a thermometer, it is necessary to state the number of degrees and whether they are above or below zero. To distinguish temperatures below zero from those above, the sign of subtraction is always placed before the former. Thus, on either scale, 12° means 12° above zero, while −12° means 12° below zero.

12. Absolute Temperature.—The freezing point was chosen as the zero point of the centigrade scale. When the Fahrenheit scale was invented, the zero point of the thermometer was placed 32° below the freezing point, as that was the lowest temperature that could then be obtained, and it was supposed that it was impossible to obtain a lower one. From the results of experiments and from calculations, however, it has been concluded that at 460° F. below zero, or 492° F. below the freezing point, there is absolutely no vibration of the molecules and consequently no heat. This is therefore called the *absolute zero*, and all temperatures reckoned from this point are called **absolute temperatures.** Absolute zero has never been reached, the lowest recorded temperature being in the neighborhood of −400° F.

13. Reckoning Absolute Temperature.—Absolute temperature may be reckoned either on the Fahrenheit or on the centigrade scale. Between 0° absolute and 0° F. there are 460 Fahrenheit degrees; between 0° absolute and the freezing point there are $460 + 32 = 492°$; while between 0° absolute and the boiling point there are $460 + 212 = 672°$. Between 0° absolute and 0° C. there are $273\frac{1}{3}$ centigrade degrees.

Absolute Temperature, Fahrenheit.—If the absolute temperature of a body, in degrees Fahrenheit, is given, its temperature on the ordinary Fahrenheit thermometer can be found by subtracting 460 from the absolute temperature. If the absolute temperature is less than 460, subtract it from 460, and the result will be the temperature below zero on the Fahrenheit thermometer.

The absolute temperature of a body, in degrees Fahrenheit, may be found from its Fahrenheit temperature by adding 460 to it, when the thermometer reading is above zero; if the thermometer reading is below zero, subtract the reading from 460. Thus, $150°$ F. $= 150 + 460 = 610°$ F., absolute; $-23°$ F. $= 460 - 23 = 437°$ F., absolute.

Absolute Temperature, Centigrade.—To find the absolute temperature of a body from its centigrade temperature, add the centigrade temperature to $273\frac{1}{3}$ when it is above zero,

correct now

and subtract it from $273\frac{1}{3}$ when below zero. Thus, 60° C. $= 273\frac{1}{3} + 60 = 333\frac{1}{3}$° C., absolute; 10° C. $= 273\frac{1}{3} - 10 = 263\frac{1}{3}$° C., absolute.

To find the centigrade temperature of a body from its absolute temperature, subtract $273\frac{1}{3}$ from the absolute temperature. Thus, 300° absolute $= 300 - 273\frac{1}{3} = 26\frac{2}{3}$° C. If the absolute temperature is less than $273\frac{1}{3}$, subtract the absolute temperature from $273\frac{1}{3}$, and the result will be the centigrade temperature below zero. Thus, 250° absolute $= 273\frac{1}{3} - 250 = 23\frac{1}{3}$° C. below zero.

14. Changing From Centigrade to Fahrenheit.—It is frequently necessary to change from one scale to the other. For example, what would 80° C. be on the Fahrenheit scale? Since the number of degrees between the freezing point and the boiling point on the centigrade scale is 100, and on the Fahrenheit 180, 1° C. will equal $\frac{100}{180}$° C. $= \frac{5}{9}$° F. Likewise, 1° C. will equal $\frac{180}{100}$° F. $= \frac{9}{5}$° F.

Rule.—*To find the Fahrenheit temperature, multiply the centigrade temperature by $\frac{9}{5}$ and add 32. If the given temperature is below zero, and when multiplied by $\frac{9}{5}$ gives a greater product than 32, subtract 32; the result is the Fahrenheit temperature below zero.*

EXAMPLE.—What will be the reading of a Fahrenheit thermometer if a centigrade thermometer indicates a temperature: (*a*) of 100° C.? (*b*) of − 30° C.?

SOLUTION.—Applying the rule,

(*a*) $100 \times \frac{9}{5} = 180$; $180 + 32 = 212$° F. Ans.

(*b*) $30 \times \frac{9}{5} = 54$. Since the given temperature is below zero and its product by $\frac{9}{5}$ is greater than 32,

$$-30° \text{ C.} = 30 \times \frac{9}{5} - 32 = 22° \text{ F. below zero. Ans.}$$

15. Changing From Fahrenheit to Centigrade. To change Fahrenheit temperatures to their centigrade values, the following rule may be used:

Rule.—(*a*) *If the given Fahrenheit temperature is 32° or greater, subtract 32 from it.* (*b*) *If the given Fahrenheit temperature is between 0° and 32°, subtract it from 32.* (*c*) *If the given Fahrenheit temperature is below 0°, add 32 to it.*

The result, in each of the three cases, multiplied by $\frac{5}{9}$ will be the centigrade temperature; in each of the cases (b) and (c), the temperature will be below zero.

EXAMPLE.—What will be the reading on a centigrade thermometer if a Fahrenheit thermometer indicates a temperature: (*a*) of 60° F.? (*b*) of 20° F.? (*c*) of – 20° F.?

SOLUTION.—Applying the rule,

(*a*) $60 - 32 = 28$; $28 \times \frac{5}{9} = 15\frac{5}{9}$° C. Ans.

(*b*) $32 - 20 = 12$; $12 \times \frac{5}{9} = 6\frac{2}{3}$° C. below zero. Ans.

(*c*) $20 + 32 = 52$; $52 \times \frac{5}{9} = 28\frac{8}{9}$° C. below zero. Ans.

16. High-Temperature Mercurial Thermometers. Until recently, instrument makers removed, as far as possible, the air from the thermometer tubes, and left the space above the mercury a nearly perfect vacuum. The boiling point of the mercury was lowered thereby, and, in consequence, mercurial thermometers could not be used for measuring temperatures much in excess of 500° F. Mercurial thermometers are now made, however, that are serviceable and accurate up to 900° F., although the ordinary boiling point of mercury is at 662°. This result is accomplished by filling the space above the mercury with gas under heavy pressure, and thereby raising the boiling point. Great care is necessary in using these instruments at high temperatures in order to avoid breakage.

17. Pyrometers.—Mercurial thermometers cannot be used for the measurement of extremely high temperatures, such as exist in furnaces. The instruments used for work of this character are called **pyrometers**. Their action usually depends on the known effects of heat on various substances, as, for example, the lengthening of metal rods, the expansion of gases, the contraction of clay blocks, and the change of color of some substances.

TRANSMISSION OF HEAT

18. Heat may be transmitted from one body to another, or from one point to another in the same body, in three ways: by *conduction*, by *convection*, and by *radiation*.

19. Conduction.—The progress of heat from a place of higher temperature to a place of lower temperature in the same body is called **conduction.** Thus, if one end of an iron rod is placed in a hot fire, the other end will soon become warm. This is due to the conduction of heat from one end of the rod to the other. The rate at which heat is conducted varies greatly in different substances. All metals are good conductors of heat, though some, such as silver and copper, are better than others, such as zinc and lead. Stone and glass are poor conductors of heat, but they are even better than wood, hair felt, or asbestos.

20. Convection.—The transfer of heat by the motion of the heated substance itself is called **convection.** It can take place only in liquids and gases. For example, if heat is applied to the bottom of a vessel containing water, the water in contact with the bottom becomes heated and rises, while the colder water above descends. A circulation is thus set up by which the heated portions of the water continually carry heat to other points in the vessel. This action is known as convection.

21. Radiation.—The transfer of heat from a hot body to a colder one, across an intervening spaoe, is called **radiation.** A person standing in front of a fire, but at some distance from it, feels a sensation of warmth that is not due to the temperature of the air, for, if a screen is placed between him and the fire, the sensation immediately ceases, which would not be the case if the surrounding air had a high temperature. Hence, bodies can send out rays of heat that can pass through the air without heating it. This is known as **radiant heat,** and the process by which it is transmitted is known as radiation. The best example of radiant heat is that received from the sun, the intervening space in this case being 93,000,000 miles.

22. When heat is transmitted by conduction or convection, some material substance forms the medium by which the transfer of heat is made. In the case of radiation, no such material medium is required. Radiant heat can be transmitted through a vacuum as well as through air.

The fact that radiant heat can be transmitted through a vacuum may be shown by the following experiment: In the top of a spherical glass vessel, Fig. 2, a thermometer *t* is fixed in such a manner that its bulb occupies the center of the vessel. The tube at the lower end of the vessel is then attached to a special kind of pump, known as an *air pump*, and all the air is drawn out of the vessel by the pump. A vacuum is thus produced inside the glass sphere. If a cloth dipped in hot water is now wrapped around the vessel, the mercury in the thermometer will be seen to rise at once. Since glass is a poor conductor of heat, it is evident that the immediate rise of the mercury was not due to heat conducted along the glass itself, but instead to the passage of radiant heat through the vacuum in the spherical vessel.

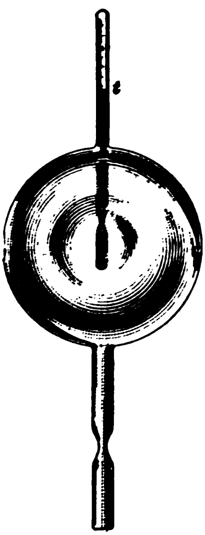

FIG. 2

23. Intensity of Radiation.—The intensity of radiant heat received by a body varies inversely as the square of its distance from the source of heat. This is easily seen by a

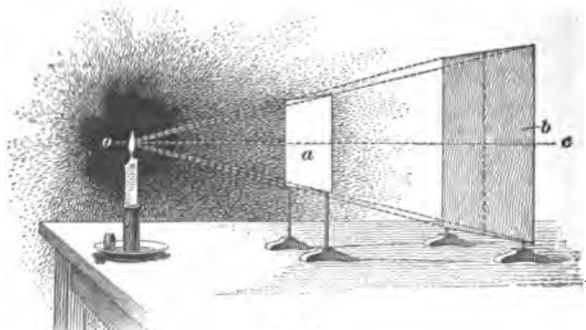

FIG. 3

study of Fig. 3, in which *a* and *b* are two plates placed at distances of 1 foot and 2 feet, respectively, from a candle flame, which is the source of heat. The square plate *b* has

twice the length and breadth and, consequently, has four times the area of the plate *a*; and the centers of both plates lie on the straight line *oc* passing through the source of heat. The heat rays radiate in all directions from the flame, but always in straight lines; and, since straight lines passing through the center of the flame and the edge of the plate *a* also touch the edge of plate *b*, it follows that the same number of heat rays fall on the plate *b* as fall on the plate *a*. If the plate *a* were placed 2 feet from the flame, that is, in the position of the plate *b*, it would receive only one-fourth the number of heat rays that previously fell on *b*, since it has but one-fourth the area of *b*. Now, the amount of heat transmitted is directly proportional to the number of heat rays. Consequently, by moving the plate twice as far away from the flame, it receives only one-fourth the amount of radiant heat; if it had been moved 3 feet away, it would have received only one-ninth the heat; and at a distance of 4 feet, it would receive but one-sixteenth the amount of heat that it received at a distance of 1 foot. Hence, the intensity of radiant heat, or the number of heat rays falling on a given area, varies inversely as the square of the distance from the source of heat.

24. Reflection and Absorption of Heat.—When radiant heat falls on the surface of a body, a part of the heat is reflected and the remainder is absorbed. The condition of the surface affects largely the proportion of heat reflected or absorbed. Thus, a highly polished surface will reflect most of the heat that falls on it and will absorb very little, while a dull rough surface will absorb much, and reflect little, of the heat. A surface that reflects much heat will not radiate much heat. A brightly polished teakettle filled with hot water will remain hot for a longer time than a dull and tarnished kettle. In the same way, a surface that absorbs heat readily will also radiate heat readily. For example, a stove coated with lampblack will give out heat much more rapidly than if it had a polished nickel surface, because lampblack radiates heat more readily than any other known substance. It likewise readily absorbs heat.

MEASUREMENT OF HEAT

25. Although heat is not a material substance, it is a physical quantity, and may be measured. If a quart of water is placed over a gas or oil flame, it will be found that it takes practically five times as long to raise the temperature of the water 5° as it does to raise it 1°, because five times as much heat has been added to the water in the first case as in the second. Now suppose that, instead of 1 quart, 2 quarts of water are placed in a vessel over the same flame. It will be found that it takes twice as long to raise the temperature of the 2 quarts 1° as it did to raise the temperature of 1 quart the same amount. The burning oil or gas below is giving off heat at a uniform rate, and of this heat twice as much has been absorbed by the 2 quarts of water as the 1 quart absorbed in acquiring the same temperature. For any given substance, it may be said that the amount of heat contained in any quantity of that substance is proportional to the product of the weight of the given quantity and its absolute temperature.

The unit commonly employed in the United States of America and in England for measuring the quantity of heat is the **British thermal unit**, which is the quantity of heat required to raise the temperature of 1 pound of water 1° Fahrenheit. Hence, 10 British thermal units will heat 1 pound of water 10°, or 10 pounds of water 1°. For convenience, the term British thermal unit is commonly abbreviated to B. T. U.

EFFECTS OF HEAT

EXPANSION

26. Introductory.—The volume of any body—solid, liquid, or gaseous—is always changed if the temperature is changed; nearly all bodies expand when heated, and contract when cooled. In solids, expansion may be considered in three ways: first, expansion in one direction, as the elongation of an iron bar; this is called **linear expansion;**

second, **surface expansion**, where the area is increased; third, **cubic expansion**, where the increase in the whole volume is considered.

27. Expansion of Solids.—In speaking of the expansion of solids, expansion in one direction, or linear expansion, is usually meant, although it should be understood that solid bodies expand in all directions. In the case of liquids and gases, since they have no definite forms, only cubic expansion can be considered. As a rule, the expansion of liquids for a given rise of temperature is greater than that of solids, and the expansion of gases is considerably greater than that of liquids. There are exceptions to this rule, however. Some liquids with low boiling points, especially liquefied gases,

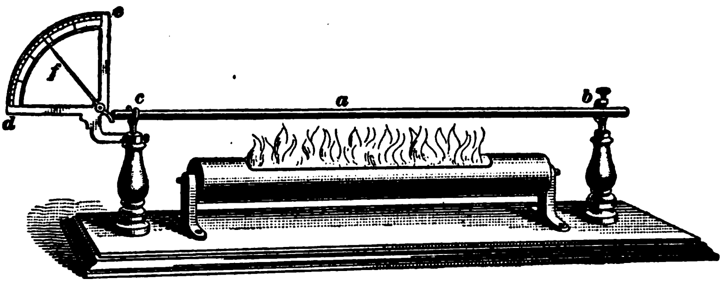

FIG. 4

expand very rapidly. For example, liquefied carbon dioxide expands four times as much as air for a given change of temperature. For equal amounts of heat added, nearly all solids and liquids expand by equal increases of volume. This is not a rigidly exact rule, but it is practically true of the great majority of substances. The expansion and contraction of a substance is a reasonably good guide to its changes of temperature. This is the case so long as the temperature does not closely approach that at which a change of state is produced—as from the solid to the liquid state, or from the liquid to the gaseous state, or vice versa. The change in the volume of any substance caused by a change of temperature bears a fairly definite and constant relation to the change of temperature. This does not mean, however,

that all substances expand and contract at the same rate. Different solids expand and contract at different rates, and the same is true of liquids. For example, copper expands and contracts much more than platinum, and alcohol more than water, for the same change of temperature.

28. In Fig. 4 is shown an apparatus for exhibiting the linear expansion of a solid body. A metal rod *a* is fixed at one end by a screw *b*, the other end passing freely through the fork *c*, held in the post, and pressing against the short arm of the indicator *f*. The rod is heated as shown, and its elongation causes the indicator to move along the arc *de*.

29. An illustration of surface expansion is afforded nearly every day in machine shops, particularly in locomotive shops, where piston rods, crankpins, etc. are shrunk in and tires shrunk on their centers. In shrinking on a tire, it is bored a little smaller than the wheel center. The tire is then heated until it is expanded enough to allow it to slide over the wheel center. It is then cooled with cold water, when it contracts, tending to regain its original size, but is prevented by the wheel center, which is a trifle larger. This causes the tire to hug the center with great force, and prevents it from coming off.

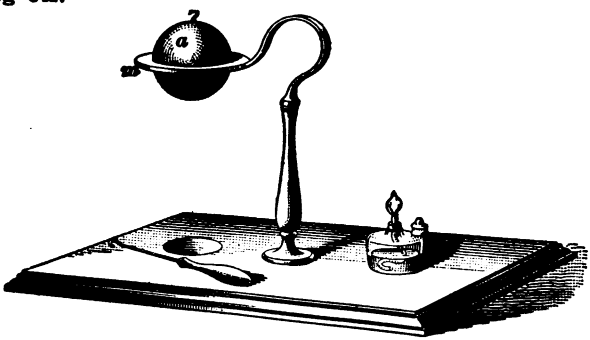

FIG. 5

30. Cubic expansion may be illustrated by means of a *Gravesandes' ring*, which consists of a brass ball *a*, Fig. 5, that at ordinary temperatures passes freely through the ring *m*, of very nearly the same diameter. When the ball

is heated, it expands so much that it will no longer pass through the ring.

31. Coefficient of Expansion.—Suppose that the temperature of the metal rod shown in Fig. 4 was 32° F. before heating, and that its length was 10 feet; and that after the temperature had been raised 1°, or to 33°, the bar was 10 feet + $\frac{1}{1200}$ inch long. The linear expansion will then be (10 feet + $\frac{1}{1200}$ inch) − 10 feet = $\frac{1}{1200}$ inch, and the ratio

TABLE I

COEFFICIENTS OF EXPANSION OF SOLIDS

Name of Substance	Linear Expansion C_1	Surface Expansion C_2	Cubic Expansion C_3
Aluminum (cast) . . .	.00001234	.00002468	.00003702
Cast iron	.00000617	.00001234	.00001850
Steel (untempered) .	.00000599	.00001198	.00001798
Steel (tempered) . .	.00000702	.00001404	.00002106
Copper	.00000955	.00001910	.00002864
Brass (cast)	.00001037	.00002074	.00003112
Silver	.00001060	.00002120	.00003180
Wrought iron	.00000686	.00001372	.00002058
Lead	.00001571	.00003142	.00004713
Zinc	.00001634	.00003268	.00004903
Tin	.00001230	.00002460	.00003690
Porcelain	.00000200	.00000400	.00000600

between this expansion and the original length of the bar will be

$$\frac{1}{1200} : 10 \times 12, \text{ or } \frac{1}{1200 \times 120} : 1, \text{ or } .000006944 : 1$$

For every increase of temperature of 1°, this rod will elongate .000006944 of its length. This number .000006944, which equals the expansion of the rod for 1° rise of temperature divided by the original length, is called the **coefficient of linear expansion.** Had the temperature of the rod been increased 100° instead of 1°, the amount of elongation would have been .000006944 × 100 = .0006944 of its length, or

.0006944 × 120 = .083328 inch, or $\frac{1}{12}$ inch. Table I gives the coefficients of expansion for a number of solids. The coefficient of cubic expansion of a solid is not often used. It is approximately three times the coefficient of linear expansion. It should be noted that the coefficients of expansion, both cubic and linear, although sufficiently exact and uniform for all ordinary purposes, are not absolutely constant.

32. The amount of expansion of metals, due to heating, may be calculated approximately by means of the following formulas:

$$l = L C_1 t \qquad (1)$$

$$a = A C_2 t \qquad (2)$$

$$v = V C_3 t \qquad (3)$$

in which L = length of any body;

l = amount of expansion or contraction due to heating or cooling the body;

A = area of any section of body;

a = increase or decrease of area of same section after heating or cooling the body;

V = volume of body;

v = increase or decrease in volume due to heating or cooling the body;

C_1 = coefficient of linear expansion, taken from Table I;

C_2 = coefficient of surface expansion, taken from Table I;

C_3 = coefficient of cubic expansion, taken from Table I;

t = difference, in degrees, of temperature between original temperature and temperature of body after it has been heated or cooled.

EXAMPLE.—How much will a bar of untempered steel, 14 feet long, expand if its temperature is raised 80°?

SOLUTION.—Since only one dimension is given, that of length, linear expansion only can be considered. From Table I, the coefficient of linear expansion per unit of length for a rise in temperature of 1° is

found to be .00000599 for untempered steel. Hence, substituting the known values in formula **1**, 14 × .00000599 × 80 = .0067088 ft., or

.0067088 × 12 = .0805056 in. Ans.

33. Expansion of Liquids.—As a rule, liquids shrink, or contract, when they freeze, and most solids expand when melted. Water is a marked exception to the general rule. If water is cooled from its boiling point, it continually contracts until it reaches 39.1° F., the temperature of maximum density, when it begins to expand, until it freezes at 32° F. On the other hand, if water at 32° F. is heated, it contracts until it reaches 39.1° F., when it commences to expand. Therefore, the density of water is greatest where this change occurs. The importance of this exception is seen in the fact that ice forms on the surface of water, since it is lighter than the warmer body of water lying at varying depths below it. Were it not for this fact, all the large bodies of water would freeze solid, and would so affect the climate of the earth that it would be uninhabitable. The coefficient of expansion of water is a very changeable quantity, varying with the temperature. In being heated from 32° to 212° F., the volume of alcohol becomes 1.11, that of mercury 1.0182, that of sea-water 1.05, and that of pure water 1.0444 times as great as the original volume.

34. Expansion of Gases.—Suppose that a cylinder *a*, Fig. 6, is closed at its upper end by a piston *b* having an area of 200 square inches and weighing 1,060 pounds. The pressure on the air due to the piston only is therefore 1,060 ÷ 200 = 5.3 pounds per square inch. If the pressure of the atmosphere is 14.7 pounds to the square inch, there is a total pressure of 14.7 + 5.3 = 20 pounds per square inch acting at the bottom surface of the piston. The contained air will, therefore, be under an absolute pressure of 20 pounds per square inch; suppose that at 32° F. it has a volume of exactly 1 cubic foot. If the temperature of the air in the cylinder is raised 1°, it will be found that the piston has moved upwards a certain amount, while the

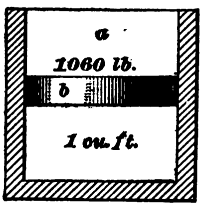

FIG. 6

pressure has, of course, been unchanged. If the air is warmed 10°, or from 32° F. to 42° F., the upward movement of the piston will be ten times as great; and for an increase of temperature of 100°, it will be one hundred times as great. The expansion of the air for an increase of 1° in temperature at any point on the scale, as, for example, from 200° F. to 201° F., is practically the same as from 32° F. to 33° F. Similarly, for temperatures below 32° F., the contraction is in the same proportion. The amount of this change of volume, whether by expansion or contraction, is $\frac{1}{491}$ of the volume of the air at 32° F., for each degree of change in temperature. The fraction $\frac{1}{491}$ is therefore called the coefficient of expansion of air. The result of this experiment is embodied in the **law of Gay-Lussac**, as follows:

If the pressure of a gas remains constant, the increase of volume per degree rise of temperature is $\frac{1}{491}$ of the volume at 32° F.

From this, it is apparent that when a gas is heated or cooled at constant pressure, the volumes will be directly proportional to the absolute temperatures.

Gay-Lussac's law may be supplemented by two others, as follows:

1. *All gases have practically the same coefficient of expansion, at constant pressure, as air; that is, $\frac{1}{492}$.*

2. *This coefficient is the same, whatever the pressure to which the gas may be subjected.*

35. The laws just mentioned are not absolutely exact, since they express the expansion of gases approximately only. However, unless a gas is compressed very highly or is cooled to a point near that at which it liquefies, these laws are quite nearly true. The fact that all gases have practically the same coefficient of expansion as air is important, inasmuch as it simplifies the work of investigating the changes in volume of a gas under changes of temperature and pressure.

For example, if a quantity of oxygen at 32° F., under atmospheric pressure, occupies a volume of 1 cubic foot, and the temperature is raised to 2,000° F., the pressure remaining

constant, the increase in volume is $\frac{1}{492}$ cubic foot for each degree rise of temperature and the total increase of volume is $\frac{1}{492}$ (2,000 − 32) = 1,968 ÷ 492 = 4 cubic feet. Hence, the final volume of the gas is 1 + 4 = 5 cubic feet.

36. The volume of a gas at constant pressure is, from the foregoing, proportional to its temperature on the absolute scale. For this reason, when the expansion or the contraction of a gas, due to changes in temperature, is to be calculated, only the absolute temperature is considered. For convenience, the absolute temperature is generally represented by T, while the ordinary temperature is represented by t. Throughout the remainder of this Section, the word pressure will be used to signify absolute pressure in pounds per square inch, and v the volume in cubic feet, unless otherwise stated.

37. In all that has been said, it has been supposed that the pressure of the gas is constant. If, however, the gas is restrained from expanding or contracting by keeping the volume constant, and heat is added as before, it is found that *the pressure of the gas increases at a rate proportional to the rise in temperature*, just as the volume did when the pressure was maintained constant, the increase in pressure for a rise of 2° being twice that for 1°.

38. The statement just made follows directly from a consideration of Mariotte's and Gay-Lussac's laws, and is a combination of the two, as may be seen from the following: Let v_0, p_0, and T_0 be the volume, pressure, and absolute temperature, respectively, of a given weight of gas under standard conditions, as, for example, 32° F. and 14.7 pounds pressure. Also, let v and p be the corresponding volume and pressure at some other temperature T. Now compress (or expand) this gas from the pressure p_0 to p, without change of temperature. To do this, as will be shown later, heat will have to be abstracted from the gas if it is compressed, or added if it is expanded, since compressing a gas heats it, and expansion cools it. The new volume of the gas will be denoted by v', but the temperature remains T_0.

Then, according to Mariotte's law, *the volume varies inversely as the absolute pressure;* or,

$$\frac{v_0}{v'} = \frac{p}{p_0} \qquad (1)$$

Next, add (or subtract) heat, keeping the pressure p constant, until the volume has changed to v. The temperature is now T; and, by Gay-Lussac's law, *the volume is directly proportional to the absolute temperature;* or,

$$\frac{v'}{v} = \frac{T_0}{T} \qquad (2)$$

These changes have taken place by two independent successive steps, whose result has been to change the gas from the original volume, pressure, and temperature v_0, p_0, and T_0, respectively, to the new volume, pressure, and temperature v, p, and T, respectively. Now, by multiplying together the left-hand members of formulas **1** and **2**,

$$\frac{v_0}{v'} \times \frac{v'}{v} = \frac{v_0 v'}{v' v}$$

But, since v' is in both numerator and denominator, it may be canceled out, and the fraction becomes $\frac{v_0}{v}$. Next, by multiplying together the right-hand members of formulas **1** and **2**,

$$\frac{p}{p_0} \times \frac{T_0}{T} = \frac{p\,T_0}{p_0 T}$$

The product of the left-hand members is equal to the product of the right-hand members, so that

$$\frac{v_0}{v} = \frac{p\,T_0}{p_0\,T}$$

By multiplying both members of this equation by $\frac{p_0 v}{T_0}$ and canceling, it is found that

$$\frac{p_0 v_0}{T_0} = \frac{p\,v}{T} \qquad (3)$$

Hence, for any addition or subtraction of heat, and any change in volume the ratio $\frac{p\,v}{T}$ is equal to $\frac{p_0 v_0}{T_0}$, and hence is constant. If, now, the volume does not change while the gas is heated or cooled, $v_0 = v$, and $\frac{p_0}{T_0} = \frac{p}{T}$, showing that,

for constant volume, the pressure changes in direct proportion to the temperature. The equation is commonly written

$$\frac{p\,v}{T} = \frac{p_1\,v_1}{T_1} = R \qquad (4)$$

in which R is a constant. For air, the value of R is .37.

Formula **4** may be applied when the quantity of gas considered is 1 pound. If some other quantity than 1 pound is taken, the formula to be used is

$$\frac{p\,v}{T} = G\,R$$

or

$$p\,v = G\,R\,T \qquad (5)$$

in which G represents the weight of the quantity of gas, in pounds, and the other letters have the same significance as before.

39. Formula **4**, Art. **38**, which is true for any of the so-called permanent gases, is the broadest expression of the law of Gay-Lussac, since from it, when the pressure, volume, and temperature of a given weight of gas are known for any particular moment, the pressure, volume, or temperature can be calculated for any other case in which the other two factors are known.

40. Beginning with Mariotte's law, the several laws of gases may be recapitulated as follows:

I. *The temperature remaining constant, the pressure of a given weight of a perfect gas varies inversely as its volume; or, the product of the pressure and volume is a constant.*

$$p\,v = p_1\,v_1 = \text{a constant} \qquad (1)$$

II. *The pressure remaining constant, the volume of a given weight of a perfect gas varies directly as its absolute temperature.*

$$\frac{v}{v_1} = \frac{T}{T_1} \qquad (2)$$

III. *The volume remaining constant, the pressure of a given weight of a perfect gas varies directly as the absolute temperature.*

$$\frac{p}{p_1} = \frac{T}{T_1} \qquad (3)$$

The truth of these rules can easily be shown. Take formula **4**, Art. **38**, $\frac{p\,v}{T} = \frac{p_1\,v_1}{T_1}$, and assume that the temperature remains constant; that is, $T_1 = T$. Then, $\frac{p\,v}{T} = \frac{p_1\,v_1}{T}$, or $p\,v = p_1\,v_1$. In the same way, let the pressure remain constant, so that $p_1 = p$. Then, $\frac{p\,v}{T} = \frac{p\,v_1}{T_1}$, or $\frac{v}{T} = \frac{v_1}{T_1}$, or $\frac{v}{v_1} = \frac{T}{T_1}$. Similarly, assuming the volume to remain constant, so that $v_1 = v$, $\frac{p\,v}{T} = \frac{p_1\,v}{T}$, or $\frac{p}{T} = \frac{p_1}{T_1}$, or $\frac{p}{p_1} = \frac{T}{T_1}$.

In formulas **1**, **2**, and **3**, it makes no difference in what units the pressures and volumes are measured, except that they must be the same throughout an example, and the pressures must always be absolute pressures.

EXAMPLES FOR PRACTICE

1. A vessel contains 25 cubic feet of gas at a pressure of 18 pounds per square inch; if 125 cubic feet of gas having the same pressure is forced into the vessel, what will be the resulting pressure?
Ans. 108 lb. per sq. in.

2. A pound of air has a temperature of 126° F. and a pressure of 14.7 pounds; what volume does it occupy? Ans. 14.75 cu. ft.

3. A certain quantity of air has a volume of 26.7 cubic feet, a pressure of 19.3 pounds per square inch, and a temperature of 42° F.; what is the weight? Ans. 2.77 lb.

4. A receiver contains 180 cubic feet of gas at a pressure of 20 pounds per square inch; if a vessel holding 12 cubic feet is filled from the receiver until its pressure is 20 pounds per square inch, what will be the pressure in the receiver? Ans. $18\frac{2}{3}$ lb. per sq. in.

5. Ten cubic feet of air having a pressure of 22 pounds per square inch and a temperature of 75° F. is heated until the temperature is 300° F.; the volume remaining the same, what is the new pressure?
Ans. 31.25 lb. per sq. in.

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41. Temperature, Pressure, and Volume of Gaseous Mixtures.—If two liquids that do not act chemically on each other are mixed together and allowed to stand, it will

be found that after a time the two liquids have separated, and that the heavier has fallen to the bottom. If two vessels of equal volume and containing gases of different densities are put in communication with each other, the gases will be found after a short time to have mixed in equal proportions. If one vessel is higher than the other, and the heavier gas is in the lower vessel, the same result will occur. The greater the difference between the densities of the two gases, the quicker they will mix. It is assumed that no chemical action takes place between the two gases. When the two gases have the same temperature and pressure, the pressure of the mixture will be the same; this is evident, since the total volume has not been changed, and unless the volume or temperature change the pressure cannot change. This property of the mixing of gases is a very valuable one, since, if gases acted like liquids, carbon dioxide (the result of combustion), which is $1\frac{1}{2}$ times as heavy as air, would remain next to the earth instead of dispersing into the atmosphere, and as a result no animal life could exist.

42. Mixtures of Equal Volumes of Gases Having Unequal Pressures.—*If two gases having equal volumes and temperatures, but different pressures, are mixed in a vessel whose volume is equal to one of the equal volumes of gas, the pressure of the mixture will be equal to the sum of the two pressures, provided the temperature remains the same as before.*

EXAMPLE.—Two vessels containing 3 cubic feet of gas, each at a temperature of 60° F. and subjected to pressures of 40 pounds and 25 pounds per square inch, respectively, are placed in communication with each other, and all the gas is compressed into one vessel. If the temperature of the mixture is also 60° F., what is the pressure?

SOLUTION.—According to the rule just given, the pressure will be $40 + 25 = 65$ lb. per sq. in. This may be proved by applications of Mariotte's law; thus, compress the gas whose pressure is 25 lb. per sq. in., until its pressure is 40 lb.; its volume may be found thus: $p v = p_1 v_1$, or $25 \times 3 = 40 \times v$; whence $v = 1.875$ cu. ft. Let communication be established between the two vessels, then the pressure will evidently be 40 lb. and the total volume $3 + 1.875 = 4.875$ cu. ft. If this is compressed until the volume is 3 cu. ft., the temperature

remaining at 60° throughout the whole operation, the final pressure may be found by the formula $p v = p_1 v_1$. Thus,

$$40 \times 4.875 = p_1 \times 3$$

and $$p_1 = \frac{40 \times 4.875}{3} = 65 \text{ lb. per sq. in}$$

as before.

43. Mixture of Two Unequal Volumes of Gas Having Unequal Pressures.—Let p_1 and v_1 be the pressure and volume, respectively, of one quantity of gas; p_2 and v_2 be the pressure and volume, respectively, of the other quantity of gas; and let P and V be the pressure and volume, respectively, of the mixture. Then, if the temperature remains constant,

$$P V = p_1 v_1 + p_2 v_2 \qquad (1)$$

That is, *if the temperature is constant, the volume, after mixture, multiplied by the resulting pressure, is equal to the volume of one quantity of gas, before mixture, multiplied by its pressure, plus the volume of the other quantity of gas multiplied by its pressure.*

From this formula, by dividing both sides of the equation by V,

$$P = \frac{p_1 v_1 + p_2 v_2}{V} \qquad (2)$$

and, dividing both sides of the equation by P,

$$V = \frac{p_1 v_1 + p_2 v_2}{P} \qquad (3)$$

EXAMPLE 1.—Two quantities of gas of the same temperature, having volumes of 6 cubic feet and $4\frac{1}{2}$ cubic feet, and pressures of $26\frac{1}{2}$ pounds and 18 pounds per square inch, respectively, are mixed together in a vessel whose volume is 10 cubic feet. The temperature of the two gases and of the mixture being the same, what is the resulting pressure?

SOLUTION.—Using formula 2, and substituting the given values,

$$P = \frac{26\frac{1}{2} \times 6 + 18 \times 4\frac{1}{2}}{10} = \frac{159 + 81}{10} = 24 \text{ lb. per sq. in.} \quad \text{Ans.}$$

EXAMPLE 2.—If the two quantities of gas in example 1 are mixed in a vessel in which the resulting pressure is 30 pounds, what is the volume of the vessel, the temperature of the two gases and of the mixture remaining the same?

SOLUTION.—Using formula 3 and substituting,

$$V = \frac{p_1 v_1 + p_2 v_2}{P} = \frac{26\frac{1}{2} \times 6 + 18 \times 4\frac{1}{2}}{30} = \frac{159 + 81}{30} = 8 \text{ cu. ft.} \quad \text{Ans.}$$

44. Mixture of Two Quantities of Air Having Unequal Pressures, Volumes, and Temperatures. If a body of air having a temperature t_1, a pressure p_1, and a volume v_1 is mixed with another volume of air having a temperature t_2, a pressure p_2, and a volume v_2, to form a volume V having a pressure P and a temperature t, either the new temperature t, the new volume V, or the new pressure P may be found, if the other two quantities are known, by the following formula, in which T_1, T_2, and T are the absolute temperatures corresponding to t_1, t_2, and t:

$$PV = \left(\frac{p_1 v_1}{T_1} + \frac{p_2 v_2}{T_2}\right) T \qquad (1)$$

It follows from this formula that

$$P = \left(\frac{p_1 v_1}{T_1} + \frac{p_2 v_2}{T_2}\right) \frac{T}{V} \qquad (2)$$

$$V = \left(\frac{p_1 v_1}{T_1} + \frac{p_2 v_2}{T_2}\right) \frac{T}{P} \qquad (3)$$

and

$$T = \frac{PV}{\left(\frac{p_1 v_1}{T_1} + \frac{p_2 v_2}{T_2}\right)} \qquad (4)$$

EXAMPLE 1.—Five cubic feet of air having a pressure of 30 pounds per square inch and a temperature of 80° F. is to be compressed, together with 11 cubic feet of air having a pressure of 21 pounds per square inch and a temperature of 45° F., in a vessel whose cubical contents is 8 cubic feet; the new pressure is required to be 45 pounds per square inch. What is the temperature of the mixture?

SOLUTION.—Substituting the given values in formula 4,

$$T = \frac{45 \times 8}{\left(\frac{30 \times 5}{540} + \frac{21 \times 11}{505}\right)} = \frac{360}{.7352} = 489.7°\text{, nearly}$$

Then, $t = T - 460 = 489.7 - 460 = 29.7°$ F. Ans.

EXAMPLE 2.—Fourteen cubic feet of air at 80 pounds pressure, and at a temperature of 100° F., is compressed with 26 cubic feet of air at 60 pounds pressure and 60° F. into a volume of 20 cubic feet; what is the resultant pressure, if the final temperature is 140° F.?

SOLUTION.—Substituting the given values in formula 2,

$$P = \left(\frac{80 \times 14}{560} + \frac{60 \times 26}{520}\right)\frac{600}{20} = 150 \text{ lb. per sq. in.} \quad \text{Ans.}$$

EXAMPLE 3.—Twelve cubic feet of gas at a pressure of 120 pounds per square inch, and at a temperature of 260° F., is compressed, together with 25 cubic feet of the same gas at a pressure of 81 pounds and a temperature of 215° F., until the final temperature is 40° F. and the pressure is 100 pounds; what is the final volume of the gas?

SOLUTION.—Substituting the given values in formula 3,

$$V = \left(\frac{120 \times 12}{720} + \frac{81 \times 25}{675}\right)\frac{500}{100} = 25 \text{ cu. ft.} \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE

1. Two vessels contain air at pressures of 60 and 83 pounds per square inch. The volume of each vessel is 8.47 cubic feet. If all the air in both vessels is removed to another vessel and the new pressure is 100 pounds per square inch, what is the volume of the vessel, the temperature being the same throughout? Ans. 12.11 cu. ft.

2. A vessel contains 11.83 cubic feet of air at a pressure of 33.3 pounds per square inch. It is desired to increase the pressure to 40 pounds per square inch by supplying air from a second vessel, which contains 19.6 cubic feet of air at a pressure of 60 pounds per square inch. What will be the pressure in the second vessel after the pressure in the first has been raised to 40 pounds per square inch? Ans. 55.96 lb. per sq. in.

3. If 4.8 cubic feet of air having a pressure of 52 pounds per square inch and a temperature of 170° is mixed with 13 cubic feet having a pressure of 78 pounds per square inch and a temperature of 265°, what must be the volume of the vessel containing the mixture, in order that the pressure of the mixture may be 30 pounds per square inch and the temperature 80°? Ans. 32.31 cu. ft.

EBULLITION AND VAPORIZATION

45. All liquids capable of boiling are also capable of evaporation. **Boiling, or ebullition,** is the formation of vapor within the mass of a liquid, due either to the addition of heat or to the reduction of the pressure below that of the boiling point of the liquid. For the most part, boiling takes place in that part of the liquid in contact with the surface through which the heat is transmitted to the liquid.

Evaporation, on the other hand, is slower than boiling and takes place at the surface only; it goes on at temperatures much below the boiling point, but more slowly as the liquid is colder; even ice will evaporate slowly.

46. To maintain evaporation, heat must be absorbed by the liquid exactly as if it were being converted into steam at the boiling temperature, instead of being converted into vapor at a lower temperature. If there is available no source of heat by which the liquid may be warmed to compensate for the heat taken from it by evaporation, the liquid itself will be cooled. Water evaporates slowly in air. Some other liquids, like alcohol, ether, bisulphide of carbon, gasoline, and naphtha, evaporate very rapidly. It is quite possible to produce a temperature below the freezing point of water by the rapid evaporation of gasoline, and in gasoline engines this phenomenon necessitates careful attention, since the gasoline does not readily pass into vapor when cooled much below the ordinary temperature of the air. To evaporate gasoline rapidly and continuously, heat must be added; in the gasoline engine, this heat may conveniently be taken from the hot gases exhausted from the cylinder, and a part of them caused to circulate around the device used for converting gasoline into vapor.

47. In a perfect vacuum, all volatile liquids, that is, liquids that give off vapors, pass instantly into vapor. This does not mean that, if the air in a closed vessel is completely exhausted, forming a perfect vacuum in the vessel, and then a quantity of any liquid is run into the vessel, the entire quantity of that liquid will pass into vapor. As soon as part of the liquid has passed into vapor, the space in the vessel ceases to be a perfect vacuum, and for any given temperature there is a point reached in the density of the vapor of that liquid beyond which no further evaporation will take place. This point is called the **saturation point** for that vapor. For example, if a quantity of water is placed in a vacuum, a portion of the water instantly passes into vapor, and the vacuum, instead of being an absolute

vacuum, becomes only a partial vacuum, since the space contains a certain amount of water vapor. After a time, no further vapor will be given off, and there will be a certain definite pressure in the vessel. If, however, the vapor given off by the water is continuously removed, so as constantly to maintain a vacuum, the water will continue to give off vapor indefinitely, or until so much heat has been abstracted from the water that it will freeze. That it is possible to freeze water by its own evaporation may be shown by experiment.

48. A flat dish, Fig. 7, containing a small quantity of water, is supported on a tripod in such a way that little or no heat can be carried to it. Beneath this dish is placed another containing sulphuric acid, which has a strong affinity for water vapor. Both dishes are placed under a glass vessel *a* and the air is removed from the inside of this vessel through the hole *b* in the plate *c*, by means of an air pump not shown in the illustration. Although the water may be at the temperature of the outside air, it will presently begin to boil. The vapor given off will be, to a large extent, absorbed by the acid, and if the air pump is worked rapidly the water will boil actively for a time and then freeze into a cake of ice. The reason for this action is easily explained. The heat required to boil the water could come from but one source, namely, the water itself, and, consequently, after considerable heat had been withdrawn, the water would become so cold that it would freeze.

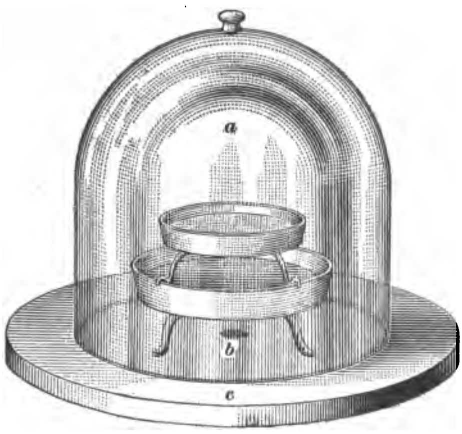

FIG. 7

49. The saturation point for any given vapor depends on the temperature. If the temperature is increased, more vapor will be given off, and a reduction of the temperature will cause a portion of the vapor to condense. An increase in the quantity of vapor in a given space implies an increase in its pressure, and consequently it follows that the pressure at which saturation occurs depends on the temperature.

Every vapor exerts a certain amount of pressure, although the pressure may be much less than that of the atmosphere. Even the mercury vapor in the almost perfect vacuum of the barometer has a slight amount of pressure. The vapors of volatile liquids, or liquids that vaporize readily, are given out much more abundantly, and their pressure under the same conditions is therefore much greater. For the same temperature, each liquid has its own vapor pressure. At 68° F., the pressure of saturated ether vapor is twenty-five times the pressure of saturated water vapor. The pressure exerted by any vapor in its saturated state is often spoken of as the **vapor tension** for that temperature.

50. The relation between the vapor tension and the quantity of vapor is expressed by two laws known as **Dalton's laws,** as follows:

I. *The pressure, and consequently the quantity, of vapor that will saturate a given space are the same for the same temperature, whether the space contains a gas or is a vacuum.*

II. *The pressure of the mixture of a gas and a vapor is equal to the sum of the pressures that each would exert if it occupied the same space alone.*

51. If a volatile liquid is added to a gas, and the resulting mixture of gas and vapor is allowed to expand so that the pressure remains unchanged, the volume of the mixture will exceed the original volume of the gas. The ratio of this new volume to the original volume of the gas is equal to the ratio between the combined pressure of the gas and vapor and the pressure of the gas alone, had the volume remained constant.

LATENT HEAT

52. Latent Heat of Fusion.—The fusion, or melting, of a solid body, whether it is ice, steel, or any other solid capable of being melted, is due to the fact that, when a certain temperature is reached, the rapid vibration of the molecules overcomes that force of attraction of the molecules for one another by which the body was enabled to retain its solid state. If a piece of ice is placed in a suitable vessel and heat is applied, the ice will gradually melt; but the temperature of the water surrounding it will not rise above 32° F. until the ice is fully melted. The ice has received heat constantly, but the heat has been utilized in changing the body from a solid to a liquid state. The heat that is added to a body to change its state, without changing its temperature, is called **latent heat.** If the state is changed from a solid to a liquid, the heat required to accomplish it is called the **latent heat of fusion.** It is customary to use 1 pound of a substance as the basis for comparing latent heats of fusion. A pound of ice requires 144 British thermal units to convert it into water at 32° F. Hence, the latent heat of ice is said to be 144. Every substance capable of being liquefied has its own latent heat of fusion, which is the number of heat units required to convert 1 pound of it from the solid to the liquid state without change of temperature.

53. Latent Heat of Vaporization.—If a quantity of water is boiled in the open air and its temperature is noted, it will be found that the temperature remains at 212° F. until the water entirely disappears. The water has absorbed a large quantity of heat while being converted into vapor without change of temperature. The amount of heat thus expended in converting a pound of water at the boiling point into steam at the same temperature is called the **latent heat of vaporization** of steam. The latent heat of steam at 212° F. is 965.8; that is, it requires 965.8 British thermal units to convert 1 pound of water at 212° F. to steam at the same temperature, under atmospheric pressure. The latent heat

of vaporization of any other liquid is the amount of heat required to change 1 pound of it from the liquid to the vapor. state without increase of temperature.

54. When a given volume of water is changed to steam at atmospheric pressure, the volume of steam formed is 1,646 times as great as the original volume of water. Thus, let the cylinder *a*, Fig. 8, be fitted with a piston *b*, and assume that the piston is weightless and frictionless. If the space beneath the piston is filled with water having a depth *h* and heat is then applied until all the water is changed to steam, it will be found that the piston has risen through a height of $d = 1{,}645\,h$; or, in other words, the steam occupies 1,646 times the volume of the water from which it is formed.

Since the piston is without weight, it follows that the pressure of the steam is constantly the same as the pressure of the atmosphere above the piston, and this is also the pressure on the water, since the pressure on a liquid is always the same as that of the vapor being evolved from it. In the production of this large amount of steam, work is done in pushing back the atmosphere through the distance 1,645 *h*, and the energy required to accomplish this is included in the latent heat of the steam.

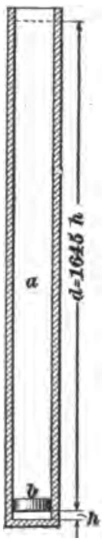

FIG. 8

55. Although the boiling point of water is commonly spoken of as 212° F., the actual boiling point is intimately related to the pressure at which evaporation takes place. Under atmospheric pressure at the sea level (14.7 pounds per square inch), the boiling point is 212° F.; but, if the pressure is increased, the point at which the water boils will be raised. At an absolute pressure of 30 pounds per square inch, the boiling point is approximately 250° F.; while at 100 pounds, absolute, the boiling point is 328° F. If the pressure is reduced, the boiling point will be lowered.

56. If a common laboratory flask *a*, like that shown in Fig. 9, is partly filled with water and boiled until all the air

is expelled, and then tightly corked and inverted, the boiling will of course stop; but if a little cold water is poured over the flask as shown, to condense the steam, the water will begin

FIG. 9

to boil again by reason of the reduction in pressure, due to the condensation of the vapor in the top of the flask. It will continue to boil until the establishment of equilibrium causes it to stop; but it may again be started boiling by pouring more water over the flask in the same way. In this manner, the boiling may be kept up until the water has reached the temperature of the room. If a quantity of water is boiling under high pressure and the pressure is suddenly reduced, a portion of the water will pass instantly into steam, abstracting heat from the remainder of the water as it does so, until the temperature is lowered to that corresponding to the pressure on the water.

57. By the **total heat of saturated steam** at any given temperature is meant the amount of heat required, first, to raise the temperature of the water from the freezing point to that temperature; and, secondly, to convert it into steam at that temperature and corresponding pressure. As the pressure and the temperature increase, the latent heat of steam is found to diminish slightly, but this is more than compensated for by the added heat required to raise the temperature of the water to the higher boiling point; so that the total heat absorbed increases slightly as the pressure and temperature increase.

SPECIFIC HEAT

58. If balls of iron, zinc, copper, lead, and tin, of equal weights, are exposed to heat for a short, but equal, length of time, as by being arranged in a row before an open fire, it

TABLE II

SPECIFIC HEATS OF SOLIDS, LIQUIDS, AND GASES

Solids	Specific Heat	Liquids	Specific Heat	Gases	Specific Heat	
					Constant Pressure	Constant Volume
Copper	.0951	Water	1.0000	Air	.23751	.16902
Gold	.0324	Alcohol	.6200	Oxygen	.21751	.15507
Aluminum	.2143	Wood spirit	.6009	Nitrogen	.24380	.17273
Wrought iron	.1138	Proof spirit	.9730	Hydrogen	3.40900	2.41226
Steel (soft)	.1165	Mercury	.0333	Superheated steam	.48050	.34600
Steel (hard)	.1175	Benzine	.4500	Carbon monoxide	.24790	.17580
Zinc	.0956	Lead (melted)	.0402	Carbon dioxide	.21700	.15350
Brass	.0939	Sulphur (melted)	.2340			
Glass	.1937	Tin (melted)	.0637			
Cast iron	.1298	Sulphuric acid	.3350			
Lead	.0314	Oil of turpentine	.4260			
Nickel	.1089	Glycerine	.5550			
Platinum	.0324					
Silver	.0570					
Tin	.0562					
Ice	.5040					
Sulphur	.2026					
Charcoal	.2410					

will be found that the lead ball is the hottest. Since all the balls are in a position to absorb equal amounts of heat, it is evident that the lead ball requires less heat to raise its temperature to a given point than the other balls. Different substances require different amounts of heat to raise equal weights of those substances 1°, water requiring more than most other substances. Hence, it is taken as a standard of comparison. Thus, *the ratio between the quantity of heat required to warm a body 1° and the quantity of heat required to warm an equal weight of water 1° is called the* **specific heat** *of the body.* This ratio is always expressed as a decimal. Hence, if the specific heat of a certain substance is said to be .1375, it is understood that the amount of heat required to raise a given weight of that substance 1° is only .1375 times the amount of heat required to raise the same weight of water 1°.

59. In Table II are given the specific heats of a number of substances.

60. Calculations involving the specific heats of various substances may be worked out by means of the following rules:

Rule I.—*To find the number of British thermal units required to raise, or to be abstracted to lower, the temperature of a body a given number of degrees, multiply the weight of the body, in pounds, by the specific heat, and by the number of degrees Fahrenheit.*

Or, $$Q = s\,G(t_1 - t) \qquad (1)$$

in which Q = number of British thermal units;
s = specific heat;
G = weight, in pounds;
t_1 = higher temperature, in degrees F.;
t = lower temperature, in degrees F.

Example 1.—How many British thermal units are required to raise 20 pounds of lead from 50° F. to 400° F., the specific heat of lead being .0314?

Solution.—Substituting values in formula **1**,

$$Q = .0314 \times 20 \times (400 - 50) = 219.8 \text{ B. T. U.} \quad \text{Ans.}$$

Rule II.—*To find the weight, in pounds, of a given substance that can be changed from one temperature to another by the application or abstraction of a certain amount of heat, divide the number of British thermal units by the product of the specific heat of the substance and the temperature difference, in degrees Fahrenheit.*

Or, $$G = \frac{Q}{s(t_1 - t)} \qquad (2)$$

in which the letters have the same meaning as in formula **1**.

EXAMPLE 2.—The specific heat of air at constant pressure being .23751, how many pounds of air can be raised 1° F. by 1 British thermal unit?

SOLUTION.—Substituting values in formula **2**,

$$G = \frac{1}{.23751 \times 1} = 4.21 \text{ lb. Ans.}$$

61. Although Table II would seem to indicate that the specific heats of various substances are constant, in the case of many solids there is a slight increase with increase of temperature. For example, the mean specific heat of iron between 32° F. and 212° F. has been found to be .1098; and between 212° F. and 570° F. it has been found to be .1218. Different substances show a great variation in this respect, and there does not seem to be any common law governing them.

The specific heat of a substance varies according to its state, whether solid, liquid, or gaseous. The specific heat of water is nearly twice as great as that of ice, and is more than twice as great as that of steam at constant pressure. In general, a substance in the solid state has a smaller specific heat than in the liquid.

62. The specific heat of a gas may be measured in two ways: first, with the gas at constant pressure, but varying volume; second, with the gas at constant volume, but varying pressure. Let c_p and c_v represent, respectively, the specific heat at constant pressure and at constant volume. Then the relation between these two specific heats is given by the ratio $\frac{c_p}{c_v}$. This ratio is usually expressed by the letter k; that is, $\frac{c_p}{c_v} = k$. For dry air the value of k is 1.405.

63. The specific heat of a gas at constant pressure is greater than that at constant volume, as will be apparent from the following: If a cylinder partly full of gas is closed by a piston, so that the gas sustains a constant pressure due to the weight of the atmosphere plus the weight of the piston, and heat is applied until the temperature of the contained gas has been raised, say, 10°, the piston will move out a certain amount owing to the expansion of the gas. Consequently, the gas has received a certain quantity of heat, and at the same time has performed work by moving the piston against the pressure of the atmosphere. The work done by moving the piston represents a portion of the energy imparted to the gas by heating. If this energy is restored to the gas by compressing it to its original volume, the gas will be heated to a certain extent by the compression. In other words, it is brought to the same condition by compression that it might have had if heated at constant volume, with the exception that its temperature is higher. This indicates that more energy has been expended on it than if it had been heated to the required temperature at constant volume; that is, the specific heat at constant pressure is greater than that at constant volume.

EXAMPLES FOR PRACTICE

1. How many British thermal units are required to change 5 pounds of ice at 15° F. into steam at 212° F.? Ans. 6,491.84 B. T. U.

2. How many pounds of ice at 32° F. can be melted by 3 pounds of steam at 212° F.? Ans. 23.87 lb.

3. How many British thermal units are required to change 13 pounds of water at 59° F. into steam at 212° F.? Ans. 14,544.4 B. T. U.

4. It is found that to raise the temperature of 20 pounds of iron from 62° F. to 63° F. requires 2.276 British thermal units; what is the specific heat of iron? Ans. .1138

5. The specific heat of silver is .057; how many British thermal units are required to raise 22 pounds of silver from 50° F. to 60° F.? Ans. 12.54 B. T. U.

6. How many B. T. U. are required to raise the temperature of 26 pounds of copper from 57° F. to 93° F. Ans. 89.01 B. T. U.

MECHANICAL EQUIVALENT OF HEAT

64. Conversion of Heat.—Heat may be described as the lowest form of energy, into which all other forms of energy tend to descend. In almost every conversion of energy from one form to another, there is a certain amount of waste, and this waste usually appears as heat. For example, the friction of any machine appears as heat, but at a temperature too low for it to be used, and it is lost. For this reason, it may be said that heat is the ultimate form into which all other forms of energy tend to be transformed.

Heat, being a form of energy, may be converted by suitable appliances into mechanical work. If the number of available heat units is known, it is possible to calculate with exactness the mechanical work that should be obtained for that quantity of heat. *Energy may readily be converted from one form to another, but can neither be created nor destroyed;* this is known as the **law of the conservation of energy.** If the heat is fully utilized, the mechanical work produced is equivalent to the quantity of heat expended.

65. The first attempt to determine, by experiment, the number of work units equivalent to one heat unit, known as the **mechanical equivalent of heat,** was made by Joule. The apparatus used consisted essentially of a box containing water which was stirred by a set of paddles kept in motion by weights attached to cords running over pulleys. The agitation of the water resulted in a rise in its temperature, and, losses by friction and radiation having been properly allowed for, the heat given up to the water, as indicated by the rise in temperature, was the equivalent of the work done by the weight in descending. As a result of these and similar experiments, *the mechanical equivalent of the British thermal unit is now generally taken as 778 foot-pounds.*

The **foot-pound** is a unit by which work is measured. It is the work expended in raising a weight of 1 pound vertically through a distance of 1 foot. The work, in foot-pounds, done by lifting a body may be found by multiplying

together the weight of the body, in pounds, and the height of the lift, in feet. Thus, if a body weighing 1,250 pounds is raised a distance of 8 feet, the work done is $1,250 \times 8 = 10,000$ foot-pounds. The heat energy of 1 British thermal unit is sufficient to raise 778 pounds a distance of 1 foot; or 1 pound a distance of 778 feet; or any other weight such a height that the product of the weight, in pounds, and the height, in feet, shall be 778. In general, the resistance, in pounds, times the distance moved, in feet, gives the work in foot-pounds. This applies to motion in any direction. Thus, if it requires a pull of 180 pounds to

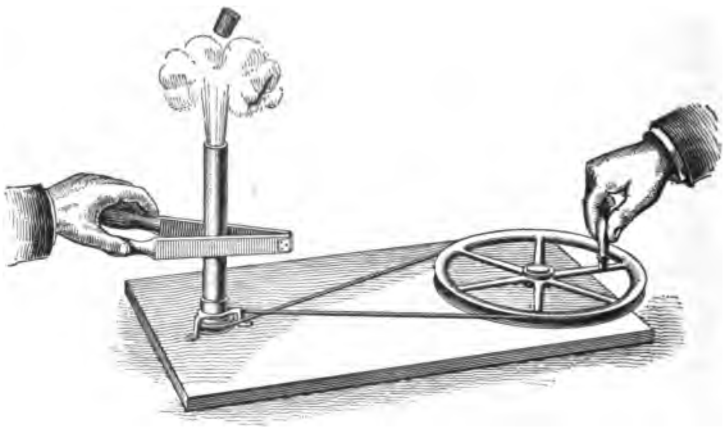

FIG. 10

draw a wagon, and the wagon is moved 300 feet, the work done is $180 \times 300 = 54,000$ foot-pounds, which is equivalent to $54,000 \div 778 = 69.41$ British thermal units.

66. Thermodynamics.—Heat may be changed into work, or mechanical energy, and work may be changed into heat. The amount of heat obtainable from a given amount of mechanical energy is always the same, being 1 British thermal unit for each 778 foot-pounds of work. If heat could be utilized without losses of any kind, the amount of work obtainable from a given amount of heat would be 778 foot-pounds for every British thermal unit supplied. The subject that treats of the laws under which heat is

transformed into work, or by which work is transformed into heat, is called **thermodynamics.**

67. An illustration of the conversion of mechanical energy into heat is given by the experiment shown in Fig. 10. A brass tube, about 7 inches in length and $\frac{3}{4}$ inch in diameter, is attached to a small wheel, and is rotated by means of a chord passing around this wheel and around a larger one turned by a handle, as shown; the tube is three-fourths full of water, and is closed with a cork. The tube is held by the clamp and made to rotate rapidly by means of the larger wheel; considerable friction is generated, which causes the water within the tube to be heated; the temperature rapidly increases, and part of the water is converted into steam, whose pressure becomes so great as to force out the cork.

Fig. 11

68. Having shown that mechanical work can be changed into heat, it will now be demonstrated that heat can be changed into mechanical work. Fig. 11 represents a cylinder *A B* partly filled with gas or air confined within the cylinder by means of the piston *P*. The gas is then under the pressure of the atmosphere, and has also an additional pressure due to the weight of the piston. If heat is applied to the bottom of the cylinder, the piston will gradually rise in proportion to the amount of heat supplied. In expanding, it will have to do work in order to raise the piston. Suppose that a rope, fastened to the piston and passed over a pulley, has a weight on the other end a trifle less than the total pressure of the atmosphere plus the weight of the piston. Now, if the gas within the cylinder is cooled, the piston will fall, owing to the combined weight of the piston and the pressure of the atmosphere, and raise the weight, thus performing work. In the first case, a certain amount of heat was supplied to the gas to do work; in the second case, heat

was *taken away* from the gas (cooled) in order that work might be done. In both cases, the amount of work done was proportional to the amount of heat supplied or taken away, and, had the work done been the same, the amount of heat supplied or taken away would also have been the same.

69. When a body free to expand is heated, two operations are performed: first, the temperature is raised and its volume is increased; secondly, the body, in expanding, overcomes the outer pressure, and thus does work. Suppose that 1 cubic foot of air is confined in a cylinder having a sectional area of 1 square foot. The height of the column of air in the vessel is then 1 foot. Let the original temperature of the air be 70° F., and let it be heated until the temperature is 100° higher, or 170° F. The new volume is determined by formula **2**, Art. **40**, to be

$$v = v_1 \times \frac{T}{T_1} = 1 \times \frac{630}{530} = 1.19 \text{ cubic feet, nearly.}$$

The increase, in volume, is $1.19 - 1 = .19$ cubic foot; and, since the area of the cylinder becomes no greater, the column of air must become .19 foot longer. Hence, the piston will be raised a distance of .19 foot. In expanding, the pressure of the atmosphere (equaling a weight of $144 \times 14.7 = 2{,}116.8$ pounds, since the area of the cylinder is 144 square inches) was overcome through a distance of .19 foot, and work was done equivalent to $2{,}116.8 \times .19 = 402.19$ foot-pounds. The greater part of the heat went to increase the temperature, and this action is called the **inner, or internal, work.** The work of overcoming the outside pressure through a certain distance, by expanding, is called the **outer, or external, work.**

70. The weight of a cubic foot of air having a temperature of 70° is found by means of formula **5**, Art. **38**, $pv = GRT$. Dividing both sides of this equation by RT,

$$\frac{pv}{RT} = G, \text{ or } G = \frac{pv}{RT}$$

Substituting the values of p, v, R, and T,

$$G = \frac{14.7 \times 1}{.37 \times 530} = .07496 \text{ pound, nearly}$$

The specific heat of air at constant pressure is .23751; hence, the total number of heat units required is

$$.07496 \times 100 \times .23751 = 1.78 \text{ heat units;}$$
$$1.78 \times 778 = 1{,}384.8 \text{ foot-pounds}$$

Since the outer work required 402.19 foot-pounds, the inner work will require

$$1{,}384.8 - 402.19 = 982.61 \text{ foot-pounds}$$

This shows that, in the case of air and gases, the outer work is a little less than half the inner work. Since the force of cohesion has no perceptible effect in the case of gases, the inner work tends only to raise the temperature, or, in other words, to increase the vibratory movement of the molecules. Consequently, if the piston in Fig. 12 were fastened down, so that the volume of the gas would remain the same, there would be no outer work, and the total work required to raise the temperature 100° would be 982.61 foot-pounds; or, to raise the temperature one degree, 9.8261 foot-pounds. The inner work may also be calculated by using the specific heat at constant volume, as indicated in Art. **60.** Thus, the inner work is

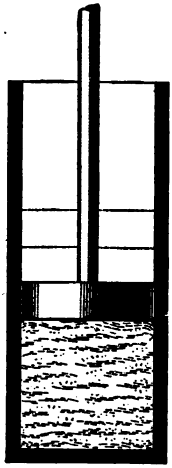

FIG. 12

$$c_v G(t_1 - t) \times 778 = .16902 \times .07496 \times 100 \times 778$$
$$= 985.7 \text{ foot-pounds}$$

The slight difference in results is due to decimals.

EXAMPLES FOR PRACTICE

1. Find the equivalent of 50,000 foot-pounds in British thermal units. Ans. 64.27 B. T. U.

2. The performance of a certain amount of work requires 926.5 British thermal units; what is the amount of work done, in foot-pounds? Ans. 720,817 ft.-lb.

3. A pull of 125 pounds is required to move a loaded car on a level track at a uniform velocity: (*a*) How many foot-pounds of

work are done in moving the car a mile? (*b*) What is the equivalent of this work in British thermal units?

Ans. $\begin{cases} (a)\ 660{,}000\ \text{ft.-lb.} \\ (b)\ 848.33\ \text{B. T. U.} \end{cases}$

4. To what height could a weight of 720 pounds be lifted by the work equivalent of 60 British thermal units? Ans. 64.83 ft.

EXPANSION AND COMPRESSION OF GASES

71. Change of State of a Gas.—If a quantity of gas has a definite pressure, volume, and temperature, it is said to have a certain **state** represented by those conditions; in other words, the state of a gas is its condition as regards pressure, volume, and temperature. If any one of these conditions is changed, the gas is said to undergo a change of state. A gas may change from one state to another in a number of ways. In practice, however, changes of state are usually the results of expansion and compression.

72. Isothermal Expansion and Compression.—If a quantity of air is placed in a cylinder fitted with a piston, and the piston is forced down quickly so as to confine the air in a much smaller space, it will be found that the temperature of the air is increased. This is due to the fact that it requires work to compress the air, and the work thus done appears as heat, raising the temperature of the air. However, if the piston is moved very slowly, the heat will pass through the cylinder walls into the surrounding atmosphere as fast as it appears, and the enclosed air will have the same temperature throughout the change of state. A change of state like that just described is known as an **isothermal compression**—that is, compression without change of temperature. If a gas is allowed to expand, and its temperature is kept constant throughout the change of state, the operation is known as an **isothermal expansion.**

73. According to formula **1**, Art. **40**, if the temperature of a gas remains constant, the product of the pressure and volume is always the same; that is, $p v = p_1 v_1 =$ a constant. Hence, this formula must represent the law governing all isothermal changes of state.

Isothermal expansion and compression may be clearly illustrated by means of a diagram like that shown in Fig. 13. Suppose that 10 cubic feet of air at a pressure of 10 pounds, absolute, is compressed isothermally until its volume is only 2 cubic feet. On the diagram, the lines *0 P* and *0 V* are drawn at right angles to each other, and equal distances or divisions are laid off on each line. The line *0 P* is called the

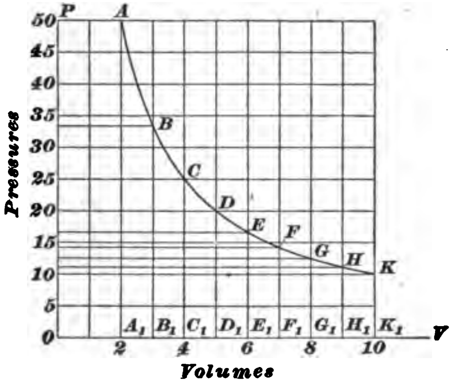

FIG. 13

axis of pressures, and *0 V* is called the **axis of volumes.** Each division laid off vertically, or in the direction of *0 P*, represents a pressure of 5 pounds; and each horizontal division, in the direction of *0 V*, represents 1 cubic foot. Hence, the state of a gas having a volume of 10 cubic feet at a pressure of 10 pounds must be represented by the point *K*, since *K* lies vertically above *10* on the axis of volumes and on the horizontal line through *10* on the axis of pressures.

74. The product of the pressure and volume at the point *K* is $10 \times 10 = 100$. Now, since the air is to be compressed isothermally, the product of the pressure and volume at any other state must be 100. Suppose that the air is compressed until its volume is only 9 cubic feet. Its pressure in that state must then be $100 \div 9 = 11\frac{1}{9}$ pounds. The point *H*, vertically above *9* and opposite $11\frac{1}{9}$ on the pressure scale, then represents that state of the gas. When the volume is compressed to 8 cubic feet, the pressure is $100 \div 8$

= $12\frac{1}{2}$ pounds, and the corresponding point is *G*, vertically above *8* and on a horizontal line passing midway between *10* and *15*. In the same way, when

v = 7 cubic feet, p = 100 ÷ 7 = $14\frac{2}{7}$ pounds
v = 6 cubic feet, p = 100 ÷ 6 = $16\frac{2}{3}$ pounds
v = 5 cubic feet, p = 100 ÷ 5 = 20 pounds
v = 4 cubic feet, p = 100 ÷ 4 = 25 pounds
v = 3 cubic feet, p = 100 ÷ 3 = $33\frac{1}{3}$ pounds
v = 2 cubic feet, p = 100 ÷ 2 = 50 pounds

These volumes and their corresponding pressures are then laid off on the diagram, locating the successive points *F*, *E*, *D*, *C*, *B*, and *A*. If, now, a smooth curved line is drawn through the points thus located, the resulting curve *K A* is called the **isothermal-compression curve.** The points on this curve from *K* to *A* represent all the successive states of the air during its compression.

75. If 2 cubic feet of air at a pressure of 50 pounds, absolute, is allowed to expand, and heat is added continually during the expansion, so as to keep the air at constant temperature, it will pass through the same states as those indicated by the curve in Fig. 13, but in reverse order. That is, the curve *A K* will represent the successive states of the air.

Hence, the curve *A K* is called the **isothermal-expansion curve.** It is now evident that, for any given weight of air, the curves of isothermal expansion and compression are identical. This is further proved, in the examples given, by the fact that the product of the pressure and the volume is the same during both expansion and compression.

76. Adiabatic Expansion and Compression.—Suppose that a quantity of gas is confined in a non-conducting cylinder, that is, a cylinder made of a material that will not conduct heat or permit the passage of heat by radiation. Under these conditions, if the gas is compressed or if it is allowed to expand, it will change its state without losing any heat to, and without receiving any heat from, outside bodies. The gas is then said to undergo **adiabatic compression or adiabatic expansion.**

77. When air is compressed adiabatically, the heat that is added to it by the work of compressing it cannot escape, and consequently the air will have a higher temperature and pressure than when compressed isothermally. This being true, it is evident that the air does not follow a curve having pv = a constant as its equation. Instead, the equation of adiabatic changes of state is pv^k = a constant. That is, the product of the pressure and the kth power of the volume is constant, in which k is the ratio of the specific heat at constant pressure to that at constant volume. As stated in Art. **62**, $k = 1.405$ for dry air.

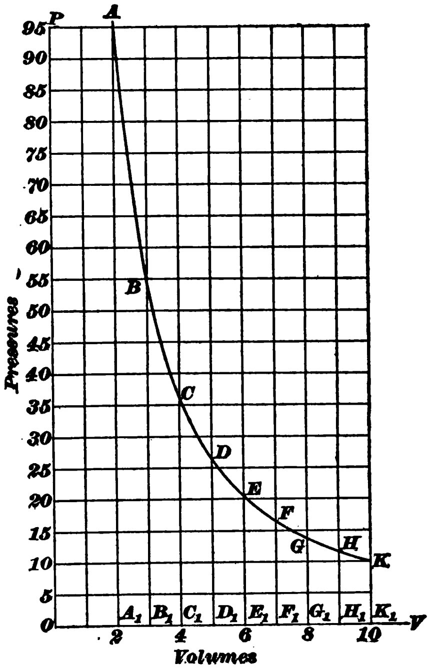

FIG. 14

78. Suppose that 10 cubic feet of air at a pressure of 10 pounds is compressed adiabatically to a volume of 2 cubic feet. The compression may be represented by a diagram, Fig. 14, as in the case of isothermal compression, Fig. 13. The original state of the air is represented by the point K, and at that point $pv^{1.405}$ = a constant. To find the value of this constant, logarithms must be used. Thus, $\log p + 1.405 (\log v)$ = log of constant, or $\log 10 + 1.405 (\log 10) = 1 + 1,405 \times 1 = 1 + 1.405 = 2.405$ = log of constant. Hence, the constant is 254.1. Now, at every other stage of the compression, the product of the pressure and the kth power of the volume must equal 254.1. Let the volume be compressed to 9 cubic feet. Then, $pv^{1.405} = 254.1$, or $p\,(9)^{1.405}$

$= 254.1$, and $p = 254.1 \div (9)^{1.405}$. Using logarithms, $\log p = \log 254.1 - 1.405 (\log 9) = 2.405 - 1.405 \times .95424 = 2.405 - 1.34071 = 1.06429$. Hence, $p = 11.6$ pounds. The point corresponding to a pressure of 11.6 pounds and a volume of 9 cubic feet is *H* on the diagram, Fig. 14.

When the volume is reduced to 8 cubic feet, $p = 254.1 \div (8)^{1.405}$, and $\log p = \log 254.1 - 1.405 (\log 8) = 2.405 - 1.405 \times .90309 = 2.405 - 1.26884 = 1.13616 = \log 13.68$. Hence, $p = 13.68$ pounds, and the point *G* represents this pressure at the corresponding volume of 8 cubic feet. When the volume is 7 cubic feet, $\log p = \log 254.1 - 1.405 (\log 7) = 2.405 - 1.18737 = 1.21763 = \log 16.51$. That is, $p = 16.51$ pounds, and *F* represents the corresponding state. When the volume is 6 cubic feet, $\log p = \log 254.1 - 1.405 (\log 6) = 2.405 - 1.09330 = 1.3117 = \log 20.5$. That is, $p = 20.5$ pounds, and *E* is the point representing the corresponding state.

By exactly the same method, the pressures corresponding to volumes of 5, 4, 3, and 2 cubic feet are found to be 26.48, 36.23, 54.28, and 95.95 pounds, respectively; and the corresponding points on the diagram are *D*, *C*, *B*, and *A*. The curve *KA* drawn through the points thus located is the **adiabatic-compression curve.**

If the 2 cubic feet of air at 95.95 pounds is allowed to expand adiabatically, the curve *AK* will represent the successive states of the air. Hence, *AK* is the **adiabatic-expansion curve** of the air, and is simply the compression curve taken in reverse order.

79. Comparison of Isothermal and Adiabatic Curves.—A comparison of the curves shown in Figs. 13 and 14 shows that, starting with equal quantities of air in like states, the adiabatic curve rises faster than the isothermal curve as the air is compressed; that is, the adiabatic-compression curve always lies above the isothermal-compression curve.

It can also be shown that, in the case of expansion, the adiabatic-expansion curve lies below the isothermal-expansion

curve. Fig. 15 shows such a comparison. The curves AD and AG are the isothermal- and adiabatic-expansion curves, respectively, of same volume of air at the same initial pressure. As shown, the adiabatic curve lies below the isothermal at all points. The points B, C, D and E, F, G are located by the methods described in connection with Figs. 13 and 14.

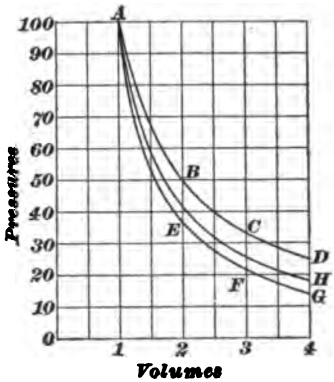

FIG. 15

80. In actual work, as, for example, in the case of the gas engine, where a quantity of heated gases expands in the cylinder and drives the piston before it, the expansion is neither isothermal nor adiabatic; that is, the curve of the expansion follows neither the law pv = a constant nor pv^k = a constant. The reason for this may be readily explained. In order to keep the temperature of an expanding gas constant, heat must be added during the expansion, and, as this is not done, the expansion is not isothermal. Furthermore, the cylinder is of metal, which conducts heat very readily. Hence, there is considerable heat lost by conduction and radiation, and so the expansion cannot be adiabatic.

In ordinary practice, it is found that the actual curve of expansion of a gas lies somewhere between the isothermal and the adiabatic. Thus, in Fig. 15, if AD and AG represent the true isothermal- and adiabatic-expansion curves of the given amount of air, the actual-expansion curve will be represented by some other line, as AH, lying between AD and AG. The equation of this curve is pv^n = a constant, in which n has a value that lies between 1 and 1.405, varying according to the different conditions under which the engine works.

As in the cases of isothermal and adiabatic expansion and compression, the expansion, according to the law pv^n = a constant, will follow the same curve as in compression, all conditions being the same.

COMBUSTION AND FUELS

CHEMISTRY OF COMBUSTION

CHEMICAL ELEMENTS

LAWS OF CHEMICAL COMBINATIONS

1. Classes of Matter.—Every body, every mass of matter, is an *element*, a *compound*, or a *mixture*. Iron, silver, sulphur, and oxygen are elements; water, alcohol, wood, lime, and carbonic acid are compounds; air, granite, brass, petroleum, and mortar are mixtures.

2. Definition of Compound.—A compound may be decomposed or divided into separate substances. For example, if an electric current is passed through water, the water slowly disappears and two gases, oxygen and hydrogen, are formed. These gases are entirely unlike, and neither resembles the water from which it was produced. Likewise, lime can be divided into two substances, calcium and oxygen. Any substance that can thus be decomposed or divided into other substances is called a **compound.**

3. Definition of Element.—There are substances, however, that have never been decomposed into other substances. By no known process can sulphur be separated into other substances; neither can iron, gold, arsenic, and many others. Substances that have never been decomposed are called **elements.**

The elements that will be referred to most frequently in this Section are given in Table I.

In referring to an element, it is customary to use simply the symbol, which is usually the first letter of the name. Thus, H stands for hydrogen, C for carbon, etc.

TABLE I

Elements	Symbols
Hydrogen . . .	H
Oxygen	O
Nitrogen	N
Carbon	C
Sulphur	S

4. Chemical Combination.—When two or more elements are brought in contact under favorable circumstances, they will combine and form a new substance that is unlike either of the elements. Of course, the new substance will be a compound. Thus, if carbon and oxygen are brought together at a high temperature, they will combine and form carbon dioxide. Hydrogen and oxygen combine to form water. Hydrogen, nitrogen, and oxygen, when combined in certain proportions, form nitric acid. A given volume of nitrogen and three times that volume of hydrogen combine and form ammonia, a gas that differs greatly from either nitrogen or hydrogen.

5. It is supposed by chemists that equal volumes of all *gases*, whether simple or compound, contain the same number of molecules. Thus, a cubic foot of hydrogen, a cubic foot of air, a cubic foot of steam, all contain the same number of molecules, when at the same pressure.

Suppose that 1 cubic foot of hydrogen gas is allowed to come in contact with 1 cubic foot of *chlorine gas* (symbol, Cl). The mixture is exposed to heat or light, and the gases combine. The process of combination is explained as follows: There is a certain attraction or affinity between the hydrogen atoms and the chlorine atoms. Each molecule of hydrogen, as well as each molecule of chlorine, contains two atoms. Under the influence of heat or light, this attraction becomes so strong that the two atoms composing the molecule of hydrogen are torn apart. Likewise, the two atoms

composing a molecule of chlorine separate. Each atom of chlorine seizes on an atom of hydrogen, and forms a molecule of an entirely new gas, namely, hydrochloric-acid gas. Since each atom of chlorine takes *one* atom of hydrogen, it is plain that the number of molecules of each gas must be the same. In other words, 1 cubic foot of chlorine requires 1 cubic foot of hydrogen to combine with it; these gases cannot be made to combine in any other proportion. For example, if 3 cubic feet of chlorine were placed in contact with 2 cubic feet of hydrogen, 4 cubic feet of hydrochloric-acid gas would be formed, and the extra cubic foot of chlorine would remain chlorine. The combination of two or more symbols representing the elements in a compound is called a **formula.** The formula for hydrochloric acid is HCl.

If hydrogen and oxygen are brought in contact and heated, they will combine and form steam (or water). But it will be found that each atom of oxygen seizes two atoms of hydrogen to form a molecule of water, and therefore the volume of hydrogen must be double the volume of the oxygen with which it combines. This is shown by the formula for water, which is H_2O; that is, two parts of hydrogen to one part of oxygen. Similarly, the formula for ammonia is NH_3; that is, three parts of hydrogen to one part of nitrogen. Again, hydrogen and carbon form a compound in which each atom of carbon seizes four atoms of hydrogen and forms a molecule of marsh gas, CH_4.

6. The formula of any compound indicates how the atoms of the elements combine to form the compound. Thus, the formula for water, H_2O, shows that two atoms of hydrogen and one atom of oxygen unite to form a molecule of water. The formula H_2SO_4 (sulphuric acid) shows that a molecule of the sulphuric acid contains two atoms of hydrogen, one of sulphur, and four of oxygen.

7. Combination by Weight.—One cubic foot of hydrogen combines with just 1 cubic foot of chlorine. But, on weighing each gas, it is found that the cubic foot of chlorine weighs 35.5 times as much as the cubic foot of hydrogen.

A cubic foot of oxygen weighs 16 times as much as a cubic foot of hydrogen.

It has been stated that equal volumes of gases contain the same number of molecules. Therefore, a cubic foot of oxygen must contain the same number of atoms as a cubic foot of hydrogen. Since the former weighs 16 times as much as the latter, it follows that an atom of oxygen weighs 16 times as much as an atom of hydrogen. Similarly, an atom of chlorine weighs 35.5 times as much as an atom of hydrogen. This ratio between the weight of an atom of any element and the weight of an atom of hydrogen is called the **atomic weight** of the element. The atomic weight of any element may be found by dividing the weight of a given volume, say 1 cubic foot, of the element, when in a gaseous state, by the weight of 1 cubic foot of hydrogen. The atomic weight, therefore, bears a direct relation to specific gravity.

TABLE II

Elements	Atomic Weights
Hydrogen, H . . .	1
Oxygen, O	16
Nitrogen, N	14
Carbon, C	12
Sulphur, S	32

8. The atomic weights of the elements most often found in fuels are given in Table II.

With the aid of these atomic weights, the composition of any substance by weight can be found when its formula is known. Take, for example, water, H_2O, which has two atoms of hydrogen to one of oxygen, and multiply the number of atoms of each by the atomic weight of the element; the results will be the parts by weight of the elements. Thus,

$$\begin{array}{ll} 2 \text{ atoms of } H \times \text{atomic weight, } 1 = & 2 \text{ parts of } H \\ 1 \text{ atom of } O \times \text{atomic weight, } 16 = & \underline{16 \text{ parts of } O} \\ & 18 \text{ parts of } H_2O \end{array}$$

Then, the water is composed of $\frac{2}{18} = 11.11$ per cent. of hydrogen, and $\frac{16}{18} = 88.89$ per cent. of oxygen.

As another example, take carbon dioxide, CO_2, in which,

$$
\begin{aligned}
&1 \text{ atom of } C \times \text{ atomic weight, } 12 = 12 \text{ parts of } C\\
&2 \text{ atoms of } O_2 \times \text{ atomic weight, } 16 = \underline{32} \text{ parts of } O\\
&\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad 44 \text{ parts of } CO_2
\end{aligned}
$$

Hence, CO_2 contains $\frac{12}{44} = 27.27$ per cent. of carbon, and $\frac{32}{44} = 72.73$ per cent. of oxygen. From these examples it is plain that the weight of the molecule, or the **molecular weight,** of water is 18, and that of carbon dioxide, 44.

9. Definition of Mixture.—Two or more elementary substances may be mixed together and yet not combine to form a new substance. They are then said to form a **mixture.** The mixture has the properties of the elements composing it. The most familiar example of a mixture is ordinary air. It is composed of oxygen and nitrogen, twenty-three parts by weight of the former to seventy-seven parts by weight of the latter. The two gases do not combine chemically; they are simply mixed.

COMBUSTION

10. Definition.—**Combustion** is a very rapid chemical combination. The atoms of some of the elements have a very great affinity or attraction for those of other elements, and when they combine they rush together with such rapidity and force that heat and light are produced. Oxygen, for example, has a great attraction for nearly all the other elements. An atom of oxygen is ready to combine with almost any substance with which it comes in contact. For carbon and hydrogen, oxygen has a particular attraction, and whenever these elements come in contact with oxygen, at a sufficiently high temperature, they combine with great rapidity. The combustion in a gas-engine cylinder is of this nature. The temperature of a small portion of the mixture of gas and air is raised by a flame or electric spark, and then the fuel charge begins to combine with oxygen taken from the air. The combination is so rapid and violent that a

great quantity of heat is given out, which suddenly raises the temperature of the mixture. *Combustion is, therefore, the rapid chemical combination of two or more substances with the production of heat and light.*

11. Examples of Combustion.—The most common examples of combustion are found in the union of wood, coal, paper, or other *combustible matter* with the oxygen of the air. Certain substances, such as sodium and water, or oxygen and phosphorus, have so intense an affinity for each other that they will unite spontaneously under ordinary conditions of temperature and pressure. A small piece of sodium dropped into water unites with the water with such intensity as to blaze while floating on its surface. Phosphorus unites with the oxygen of the air slowly at ordinary temperatures, producing a hardly perceptible warmth, but if a little piece of phosphorus is warmed, even by rubbing it, it will burst instantly into flame. If a bit of phosphorus is dropped into a jar of pure oxygen, it will ignite spontaneously.

12. Products of Combustion.—The products of combustion are usually, but not always, gases or vapors. Consequently, if one of the original substances is a solid or liquid, such as wood, coal, oil, or the like, the products of the combustion thereof will greatly exceed in volume the original substance. The tremendous expansive force of a gunpowder explosion is due to this fact.

Liquids never burn as liquids. To produce combustion, they must first be vaporized and their vapors mixed with air in suitable proportions. This process requires the addition of heat, which may be secured by absorption or by radiation from surrounding objects, and which will come mainly from the combustion itself after that has been started. Liquids that volatilize at ordinary temperatures are highly dangerous if their vapors are inflammable, and should be handled with extreme care. If, like kerosene and the heavier oils, they do not volatilize at ordinary temperatures, they are not so dangerous. Alcohol and gasoline both give off inflammable vapors at ordinary temperatures.

13. When the affinity of two substances is not so great as to make them spontaneously combustible, it is necessary to start combustion by bringing some portion of the substances to the temperature of combustion. In the case of gases or combustible vapors, the heat for ignition may be derived from heated metals, from a flame, or from an electric spark. The electric spark, although very small, is of a very high temperature, and is amply sufficient for the purpose, provided that the proportions of the two combustibles or of the combustible and the oxygen adjacent to the spark are approximately those required for chemical union. A strong spark, however, will cause a more rapid spread of the flame than a weak spark.

14. When carbon and oxygen combine, they form carbon dioxide, CO_2; when hydrogen and oxygen combine, they form water, H_2O. These are called the **products of combustion.** When, as is ordinarily the case, the oxygen is obtained from the air, the nitrogen of the air passes into the gas-engine cylinder along with the oxygen. It takes no part in the combustion and passes off through the exhaust with the carbon dioxide.

All the fuel oils and gases, including illuminating gas, are chemical compounds of hydrogen and carbon, and are called **hydrocarbons.** When burned in oxygen, they split up, the hydrogen and carbon uniting separately with the oxygen in the air and producing water vapor and carbon dioxide, respectively. It is this water vapor that causes the condensation on the windows of a cold room in which many gas jets or oil lamps have been burning for some time.

AIR REQUIRED FOR COMBUSTION

15. It has been shown that carbon dioxide is composed by weight of 12 parts of carbon to 32 of oxygen. Hence, to burn 1 pound of C requires $\frac{32}{12} = 2\frac{2}{3}$ pounds of O. If the O is taken from the air, it will take $2\frac{2}{3} \div .23 = 11.6$ pounds of air to supply the $2\frac{2}{3}$ pounds of O. This is because only

23 per cent., by weight, of air is O. The combustion of 1 pound of C may be represented as follows:

Mixture, in Pounds			Elements, in Pounds			Products, in Pounds	
Carbon,	1		Carbon,	1	=	Carbon dioxide,	3.67
Air,	11.6	=	Oxygen,	2.67			
			Nitrogen,	8.93		Nitrogen,	8.93
Total,	12.6		Total,	12.6		Total,	12.6

That is, 1 pound of C requires for its complete combustion 11.6 pounds of air. Of this air, 2.67 pounds is O, which combines with the pound of C, forming 3.67 pounds of CO_2. The 8.93 pounds of nitrogen contained in the air passes off with the CO_2 and takes no part in the combustion.

Take, next, the complete combustion of 1 pound of hydrogen. The product of the combustion is water, H_2O. It has been shown that H_2O is composed, by weight, of 2 parts of H to 16 parts of O. Hence, 1 pound of H requires $16 \div 2 = 8$ pounds of O to unite with it. The air required to furnish 8 pounds of O is $8 \div .23 = 34.8$ pounds. The process of combustion is, therefore, as follows:

Mixture, in Pounds			Elements, in Pounds			Products, in Pounds	
Hydrogen,	1		Hydrogen,	1	=	Water,	9
Air,	34.8	=	Oxygen,	8			
			Nitrogen,	26.8		Nitrogen,	26.8
Total,	35.8		Total,	35.8		Total,	35.8

16. There is one other case that may occur; the combustion of C may not be complete. If insufficient air or O is supplied to the burning C, it is possible for the C and O to form another gas, carbon monoxide, CO, instead of carbon dioxide, CO_2.

The combustion of 1 pound of C to form CO, of course, requires only one-half of the O that would be necessary to form CO_2, because, in forming CO, one atom of C unites with one atom of O instead of two. To burn 1 pound of C to CO_2 requires 11.6 pounds of air. To burn it to CO will,

therefore, require but 5.8 pounds of air, the products of combustion being as indicated below:

Mixture, in Pounds		Elements, in Pounds		Products, in Pounds	
Carbon,	1	Carbon,	1	= Carbon monoxide,	2.334
Air,	5.8 =	Oxygen,	1.334		
		Nitrogen,	4.466	Nitrogen,	4.466
Total,	6.8	Total,	6.8	Total,	6.8

Since an additional supply of 5.8 pounds of air would be required to convert 2.334 pounds of CO into CO_2, the complete combustion of 1 pound of CO would require $5.8 \div 2.334 = 2.48$ pounds of air. The truth of this statement is verified as follows: By referring to the atomic weights of C and O, it will be seen that 1 pound of CO is composed

TABLE III

Name of Gas	Cubic Feet of Air Required per Cubic Foot of Gas	Products of Combustion
Hydrogen, H	2.38	Water Nitrogen
Marsh gas, CH_4	9.52	Water Carbon dioxide Nitrogen
Sulphureted hydrogen, H_2S	7.14	Water Sulphur dioxide Nitrogen
Carbon monoxide, CO ..	2.38	Carbon dioxide Nitrogen

of 12 parts, by weight, of C and 16 parts, by weight, of O; consequently, to complete the combustion of 1 pound of CO, $\frac{16}{16+12} = \frac{16}{28}$, or .57 pound of O is required. As air contains only 23 per cent. of O, the amount of air required will be $.57 \div .23 = 2.48$ pounds. Carbon monoxide, CO, is

seldom formed in the gas-engine cylinder, but it is one of the principal constituents of water gas and producer gas.

17. In gas-engine practice, it is not customary to deal with the weights of the gases employed, since gases are invariably measured in cubic feet. To calculate the amount of air required for the complete combustion of any gas when its composition by volume is known, Table III and the formula for hydrocarbons afterwards given may be used.

18. To Find Volume of Air Required for Complete Combustion of Any Hydrocarbon.—All formulas for hydrocarbons may be expressed by the general formula C_nH_m, in which n represents the number of atoms of C, and m the number of atoms of H in one molecule of the hydrocarbon.

19. Every atom of C burning to CO_2 requires two atoms of oxygen. Every 2 atoms of H requires one atom of O. The number of atoms of O required for the complete combustion of any hydrocarbon would then be $2n + \frac{m}{2}$, or twice the number of atoms of C plus one-half the number of atoms of H contained in one molecule of the hydrocarbon.

20. According to chemical theory, each volume of the gas requires one-half as many volumes of O as there are atoms of O in the compound. The volume of O required for the complete combustion of onc volume of the hydrocarbon is, then, equal to

$$\frac{2n + \frac{m}{2}}{2} = n + \frac{m}{4}$$

Since the air contains 21 per cent., by volume, of oxygen, this quantity must be divided by .21 or multiplied by $\frac{1}{.21} = 4.76$. The formula for the amount of air necessary for the complete combustion of one volume of any hydrocarbon is, then,

$$V = \left(n + \frac{m}{4}\right)4.76$$

in which V represents the volume of air required.

EXAMPLE.—How many cubic feet of air are required for the complete combustion of 1 cubic foot of butane, C_4H_{10}?

SOLUTION.—Butane contains four atoms of C and ten atoms of H. Hence, substituting in the formula $V = \left(n + \frac{m}{4}\right)4.76$,

$$V = (4 + \tfrac{10}{4})4.76 = 6.5 \times 4.76 = 30.94 \text{ cu. ft. Ans.}$$

21. When a gas consists of a mixture of various hydrocarbons, the proportion of each hydrocarbon must be ascertained before the required volume of air is completed.

EXAMPLE.—What volume of air is required for the complete combustion of 1 cubic foot of a gas having the following composition?

CONSTITUENTS OF GAS	PER CENT.
Methane, CH_4	65
Ethane, C_2H_6	25
Propane, C_3H_8	10
	100

SOLUTION.—Using the formula of Art. **20**, 1 cu. ft. of CH_4 requires

$$(1 + \tfrac{4}{4})\,4.76 = 2 \times 4.76 = 9.52 \text{ cu. ft. of air}$$

One cu. ft. of C_2H_6 requires

$$(2 + \tfrac{6}{4})\,4.76 = 3.5 \times 4.76 = 16.66 \text{ cu. ft. of air}$$

One cu. ft. of C_3H_8 requires

$$(3 + \tfrac{8}{4})\,4.76 = 5 \times 4.76 = 23.8 \text{ cu. ft. of air}$$

Since there is $\frac{65}{100}$ cu. ft. of CH_4 in 1 cu. ft. of the gas, the volume of air required for the complete combustion of the CH_4 will be $9.52 \times .65 = 6.19$ cu. ft. of air. Similarly, it will require $16.66 \times .25 = 4.17$ cu. ft. of air to burn the C_2H_6 and $23.8 \times .10 = 2.38$ cu. ft. of air to burn the C_3H_8. The complete combustion of the entire cubic foot of the gas will then require the sum of the amounts necessary to consume the separate portions, or

$$6.19 + 4.17 + 2.38 = 12.74 \text{ cu. ft. Ans.}$$

22. Nearly all gases employed for engine purposes contain, besides hydrocarbons, a greater or less amount of free H, CO, CO_2, N, and occasionally small percentages of H_2S (sulphureted hydrogen) and O. To find the amount of air required to completely burn a mixture containing these gases, proceed in the same manner as in the example of Art. **21**, using the quantities of air required for H, H_2S, and CO given in Art. **17**, and making, of course, no computation for the CO_2 and N, since these two gases are

incombustible. When O is present, the amount of O must be multiplied by 4.76, and this result subtracted from the amount of air required for the inflammable gases contained in the mixture, as illustrated in the following example:

EXAMPLE.—Analysis of a certain natural gas shows it to have the following composition:

Constituents of Gas	Per Cent.
H	22.0
CH_4	67.0
C_2H_4	5.0
C_3H_8	1.0
CO	.6
CO_2	.6
N	3.0
O	.8
	100.0

What volume of air is required for the complete combustion of 1 cubic foot of this gas?

SOLUTION.—Taking the combustible gases in the order given,

	Cubic Feet of Air
H requires $2.38 \times .22 =$	.5236
CH_4 requires $9.52 \times .67 =$	6.3784
C_2H_4 requires $(2+\frac{4}{4})\,4.76 = 3 \times 4.76 = 14.28$; $14.28 \times .05 =$	.7140
C_3H_8 requires $(3+\frac{8}{4})\,4.76 = 5 \times 4.76 = 23.80$; $23.80 \times .01 =$	.2380
CO requires $2.38 \times .006 =$	.01428
Total air required for complete combustion of inflammable gases	7.86828
Subtract, for O contained, $4.76 \times .008 =$	.03808
Total air required to burn mixture	7.83020

Hence, each cubic foot of this natural gas requires 7.8302 cu. ft. of air for its complete combustion. Ans.

23. In gas-engine practice, the proportions of C and H, by weight, should be determined, since volumetric measurements usually complicate the determinations to an extent that is very often confusing. When these proportions are known, the quantities of air required for combustion are as shown in the following scheme:

Gas	Air Required per Pound of Gas at 62° F.	Products of Combustion
Hydrogen	34.8 lb. or 457 cu. ft.	Water Nitrogen
Carbon burned to CO_2	11.6 lb. or 152 cu. ft.	Carbon dioxide Nitrogen

24. The gasolines and oils in common use are composed of hydrocarbons, with sometimes a small percentage of water and sulphur compounds. When the percentages of C and H are known, the air required for the combustion of 1 pound of the fuel is easily found. For example, suppose a certain oil is 90 per cent. C and 10 per cent. H. To burn the C requires $152 \times \frac{90}{100} = 136.8$ cubic feet of air; to burn the H requires $457 \times \frac{10}{100} = 45.7$ cubic feet of air. Hence, to burn 1 pound of the oil requires $136.8 + 45.7 = 182.5$ cubic feet of air.

Let V = number of cubic feet of air required for combustion of a given fuel;

C = percentage of C, expressed as so many parts in 100;

H = percentage of H, expressed as so many parts in 100.

$$V = 152 \times \frac{C}{100} + 457 \times \frac{H}{100}$$

or

$$V = 1.52\,(C + 3H), \text{ very nearly}$$

Example.—A certain oil contains 84 per cent. of carbon and 16 per cent. of hydrogen; how many cubic feet of air is required for the complete combustion of 1 pound of this oil?

Solution.—According to the formula,
$V = 1.52\,(C + 3H) = 1.52\,(84 + 3 \times 16) = 200.64$ cu. ft. Ans.

HEAT OF COMBUSTION

25. Heat Value.—The quantity of heat produced by the complete combustion of various gases and petroleum products has been found by experiment. This quantity is known as the **heat value** of the fuel, and represents the *greatest* amount of heat that can be obtained from a given quantity of the fuel by complete combustion. No accurate

TABLE IV

MIXTURES OF AIR AND GASES, AND RESULTING HEATS OF COMBUSTION

Fuel	Chemical Proportions	Weight of Gas at 32°, per Cubic Foot Pound	Volume of 1 Pound of Gas at Atmospheric Pressure Cubic Feet		Volume Required to Burn 1 Cubic Foot of Gas Cubic Feet		Weight Required to Burn 1 Pound of Gas Pounds		Specific Heat of Gas at Constant Pressure	Heat of Combustion	
			32°	62°	O	Air	O	Air		B. T. U. per Pound of Fuel	B. T. U. per Cubic Foot of Gas at 62°
Oxygen, O	23 lb. O + 77 lb. N = 100 lb. air	.08927	11.20	11.88					.21751		
Nitrogen, N	21 vol. O + 79 vol. N = 100 vol. air	.07847	12.77	13.55					.24380		
Hydrogen, H	$2H + O = H_2O$	.00562	178.80	189.80	.5	2.38	8.00	34.80	3.40900	62,000	327
Carbon, C	$C + O = CO$									4,400	
Carbon, C	$C + 2O = CO_2$									14,600	
Carbon monoxide, CO	$CO + O = CO_2$	.07704	12.77	13.55	.5	2.38	.57	2.48	.24790	4,385	324
Carbon dioxide, CO_2	1 lb. C + 2.66 lb. O = 3.66 lb. CO_2	.12323	8.12	8.60					.21700		
Methane (marsh gas), CH_4	$CH_4 + 4O = 2H_2O + CO_2$	.04538	22.37	23.73	2.0	9.52	4.00	17.40	.59290	23,976	1,010
Ethylene (olefiant gas,) C_2H_4	$C_2H_4 + 6O = 2H_2O + 2CO_2$	.07830	12.77	13.55	3.0	14.28	3.43	14.90	.40400	21,476	1,585
Ethane, C_2H_6	$C_2H_6 + 7O = 3H_2O + 2CO_2$	.08369	11.94	12.67	3.5	16.66				22,356	1,765
Benzol vapors, C_6H_6	$C_6H_6 + 15O = 3H_2O + 6CO_2$	.22363	4.471	4.74	7.5	35.7			.37540	18,183	3,836
Acetylene, C_2H_2	$C_2H_2 + 5O = H_2O + 2CO_2$	.07251	13.79	14.63	2.5	11.9				21,421	1,464

rule has yet been devised by which to compute the heat value of any chemical compound from its formula and the heat values of the elements of which it is composed. Hence, the heat values of compounds must be found by a separate determination for each one in the laboratory. The heat developed by the combustion of some of the commoner fuels and gases is given in Table IV. In the case of carbon, the heat developed by its complete combustion, forming CO_2, and the heat of its partial combustion to CO, are given; also the heat of combustion of CO to CO_2.

26. Heat Value of a Mixture.—The **heat value of a mixture** may be found from the heat values of the substances of which it is composed and the percentage of each substance. If h_1, h_2, h_3, etc. represent the heat values of the substances forming the mixture, and p_1, p_2, p_3, etc. represent the percentage of each substance, the heat value of the mixture will be represented by the following formula:

$$h_m = p_1 h_1 + p_2 h_2 + p_3 h_3 + \text{etc.}$$

EXAMPLE.—A certain gas has the following composition:

CONSTITUENTS OF GAS	PER CENT.
Hydrogen, H	20
Marsh gas, CH_4	70
Acetylene, C_2H_2	10

What is the heat value per cubic foot of the mixture?

SOLUTION.—Referring to Table IV, the heat values per cubic foot of these gases are seen to be 327, 1,010, and 1,464 B. T. U., respectively. Apply the formula just given. $p_1 = .20$, $p_2 = .70$, and $p_3 = .10$. Also, $h_1 = 327$, $h_2 = 1{,}010$, and $h_3 = 1{,}464$. Substituting, $h_m = .20 \times 327 + .70 \times 1{,}010 + .10 \times 1{,}464 = 65.4 + 707 + 146.4 = 918.8$ B. T. U. Ans.

27. Temperature of Combustion.—The theoretical temperature of the combustion of a given fuel can easily be calculated. Making no allowance for losses of heat, and supposing that just enough air is furnished for the combustion, burning carbon should have a temperature about 4,940° above zero; while burning hydrogen should have a temperature of about 5,800° above zero. In practice, these temperatures are never attained, on account of heat losses. Heat usually escapes so rapidly through the cylinder walls, and so much

heat is needed to raise the temperature of the excess of air, that the temperature of the gases immediately after complete ignition never approaches the theoretical.

If the actual temperature of combustion is known, it is possible to determine the increase of pressure that a given quantity of gas will undergo. As the process of combustion is practically the conversion of one mixture of gases into another, it follows that *for equal temperatures* the volume of the products of combustion will not necessarily be greater than that of the mixture before combustion. In fact, it has been found that, for the ordinary gas-engine fuels, the volume of the products of combustion is slightly less, and, when the water vapor in them condenses, the volume is very much smaller. However, the condensation of this vapor does not need to be considered here, since the temperatures from combustion, until the gases are discharged, are far above the boiling point of water.

DISSOCIATION

28. An important cause of the lowering of the temperature is the phenomenon known as **dissociation.** It may be defined as the decomposition due to the high temperatures generated in the gas-engine cylinder. Water in the form of steam, for instance, commences to decompose into hydrogen and oxygen at a temperature between 1,660° and 1,830° F. At about 2,200°, dissociation is increased; but at this temperature, the limit of dissociation appears to be reached. Since a temperature of 2,800° is quite frequently produced in the gas engine, it follows that dissociation becomes an important factor in the determination of what is taking place during the cycle.

Besides reducing the temperature from what might be obtained, dissociation prevents the complete combustion of the fuel at the beginning of the stroke. Hence, heat is constantly being added to the contents of the cylinder as the piston proceeds and the temperature of the mixture falls, allowing the dissociated gases to combine.

29. A good example of the effect of dissociation is shown by the temperature of the flame produced by the burning of hydrogen and oxygen. Theoretically, the temperature of the flame should be over 10,800°, while the temperature actually realized is but 4,500°, or a little less than one-half of the theoretical.

When a mixture of hydrogen and oxygen is exploded in a closed vessel, the theoretical temperature, when no dissociation occurs, is over 16,000°. The highest temperature yet obtained in experiments with these gases is less than 7,000°. Mixtures of hydrogen and air give much lower temperatures. Although dissociation cannot be held responsible for all of this difference of temperature, it certainly of all causes plays the most important part.

EXAMPLES FOR PRACTICE

1. How many cubic feet of air is required for the complete combustion of 1 cubic foot of: (*a*) propylene, C_3H_6? (*b*) butylene, C_4H_8?

Ans. { (*a*) 21.42 cu. ft.; (*b*) 28.56 cu. ft. }

2. Required, the volume of air necessary for the complete combustion of 8 cubic feet of gas having the following composition:

Constituents of Gas	Per Cent.
Methane, CH_4	72
Propane, C_3H_8	12
Butylene, C_4H_8	5
Butane, C_4H_{10}	11

Ans. 116.33+ cu. ft.

3. Required, the number of cubic feet of air necessary for the complete combustion of 23 cubic feet of Leechburg natural gas. This gas has the following composition, by volume:

Constituents of Gas	Per Cent.
H	4.79
CH_4	89.65
C_2H_4	4.39
C_2H_6	.56
CO	.26
CO_2	.35

Ans. 216.5+ cu. ft.

4. An oil is 88 per cent. carbon and 12 per cent. hydrogen; how many cubic feet of air is required for the complete combustion of 1 pound? Ans. 188.48 cu. ft.

5. Required, the heat value per cubic foot of a gas having the following composition:

Constituents of Gas	Per Cent.
H	12
CH_4	73
C_2H_4	13
CO	2

Ans. 989.07 B. T. U.

FUELS

PETROLEUM AND ITS PRODUCTS

OCCURRENCE AND ORIGIN

30. In its original or crude state, **petroleum** is usually found as a dark-brown liquid. Its color, however, varies from that of pure water to a tarry black. It has a greasy feeling and a fatty appearance, the heavier and darker kinds having the consistency of heavy molasses. Usually, the odor is disagreeable, being particularly offensive when sulphur is present in the oil. Water-clear petroleum is of very rare occurrence, and is found only in Persia and at Smith's Ferry, Pennsylvania. Petroleum, like many minerals, is found at various depths beneath the earth's surface. It has been found in springs, oozing from the ground, in shallow wells, and in artesian wells many thousand feet deep. In the United States, it is found in one or the other of its various forms in almost every state. In the state of Pennsylvania, the Indians formerly gathered the oil from the surface of the water in salt marshes, while in the Russian Caucasus large springs have been known for centuries. There is scarcely any division of the earth's surface that has not a deposit of petroleum. The most important of these, however, are the deposits at Baku, on the shores

of the Caspian Sea, those in Western Pennsylvania and California, and the recently opened Texas deposits.

31. In Pennsylvania, New York, and West Virginia, petroleum is found in sandstone of various geological formations in the shape of several distinct layers, known as the first, second, third, fourth, and fifth oil sands. Wells of various depths are thus found; while a well, say 60 or 70 feet deep, may be drilled to the first sand and produce oil; another must perhaps be drilled to the third or fourth sand before oil is found, and may be 600 feet or more deep.

32. Petroleum was at first gathered from shallow wells and from excavations in the neighborhood of deposits close to the surface. The latter were usually filled indirectly from natural-flowing wells close by. It was later found that, by boring, there could be produced artesian oil wells whose daily output of oil was enormous. An *artesian* oil well is one in which the oil rises to the surface without having to be pumped; quite frequently it jets out in the form of a fountain many feet in height. The Droobja fountain in the Russian Caucasus spouted up to a height of between 200 and 300 feet, while the Markoff fountain sent up a column of oil mixed with sand 400 feet high. In the Pennsylvania oil fields, the driller has often had his set of heavy iron tools thrown out of the well by the rush of gas and oil.

The great waste that was formerly caused by the oil flowing away on the surface of the ground is now avoided. The driller has a cap prepared beforehand, placing it on top of the well very soon after the first flow of oil. In course of time, the pressure that causes the oil to rise to the surface subsides, and the oil has to be pumped from below the surface.

33. Petroleum, as usually found, comes from beds of sand, or porous rocks of various kinds, where, in the little crevices and spaces, it has found room for storage. In many cases, it has not been formed there, but has been forced in by pressure from the original deposit. These reservoirs are called *secondary deposits*, the sand or loose rock being often found in crevices of the harder rocks, so that very often,

in fact nearly always, the best wells are in rows. Such rows are known as *belts*. These rows are not usually straight, but take on a gentle curve, the curve following a crevice in the

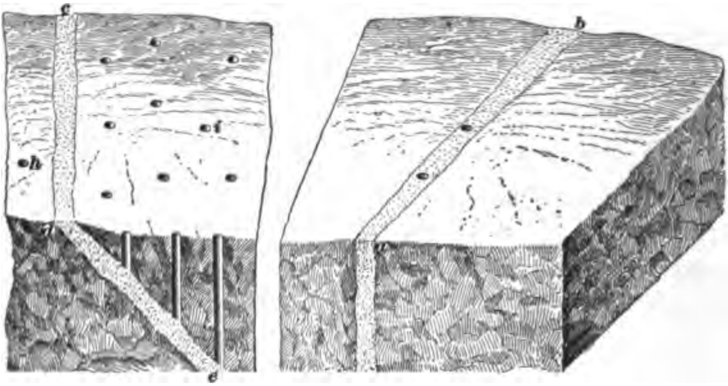

FIG. 1

rock, as *a b* or *c d*, Fig. 1. This crevice is usually filled with various deposits, generally sand and loose rock, which contain the oil. In the vertical crevice *a b*, the line on which oil may be found is very narrow. The crevice *c d* gives a wider

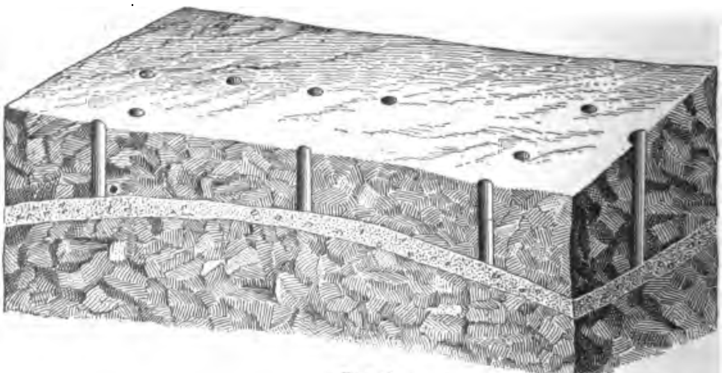

FIG. 2

oil line, but the wells most distant from the line *c d* must be drilled deeper. It can readily be seen that a well sunk at *h* would be dry, no oil being found, while a well at *i* would strike oil at a great depth.

Sometimes the layer of sand is nearly level, as in Fig. 2, and oil wells can be sunk over a wide space. Oil is also found in pockets; and one well will sometimes yield a large output, while others, close about it, show little or no oil.

34. The origin of petroleum is a matter of some uncertainty, but the available facts of geology seem to support the supposition that the oil is of animal rather than of mineral origin. The accepted theory on the subject may be stated about as follows: Many thousands of years ago, the ocean covered, in addition to its present bed, a large portion of what is now dry land. Animal life in those seas was very abundant, and, from time to time, earthquakes, landslides, and strong currents in the ocean buried large numbers of animals, both on the present dry land and under the sea. Oxygen is necessary for the destruction of animal matter by decay; and the air and water not being in contact with these large quantities of animal remains, another sort of transformation took place. In the course of time, and under high pressures produced by circumstances that cannot be explained in a treatise of this nature, the softer portions of these animal remains were changed to petroleum, the bones being wholly or partially transformed into rock.

35. In original deposits (those places where the animal remains have been changed into petroleum), skeletons of fishes and various animals have been found, with petroleum surrounding them. It is known that the petroleum was formed there, and came from nowhere else, from the fact that these skeletons, with the surrounding oil, are enclosed in solid rock, through which nothing could have passed from the outside. There is scarcely any doubt of this being the true origin of the large quantities of petroleum found in all parts of the world.

EXTRACTION AND TRANSPORTATION

36. Extraction.—The extraction of petroleum from its deposits in the earth presents various degrees of difficulty, depending, of course, on the locality. Although in some

cases petroleum flows to the surface without previous drilling, the boring of wells to various depths, up to 4,500 feet, is the method now adopted. The depth, of course, is not always the same, on account of the different locations of the oil deposits. Some wells flow to the top of the ground, while, in others, the oil must be pumped to the surface. In all cases a derrick is first erected over the spot selected for the well, and the drilling is done by means of a bar of steel, shaped like a chisel, which is alternately lifted and dropped on the rock, the broken rock, etc. being pumped out every little while with the aid of water.

37. Transportation.—In the early days of the oil industry, the transportation of both crude and refined oil was accomplished by means of barrels loaded on carts or railroad cars. Later tank wagons and tank cars, built of sheet iron, took their places, and are still employed to a great extent. But pipe lines, similar to the gas and water mains that underlie all our cities and towns, are now in general use. These pipes are made of wrought iron, with screwed joints. They are laid a few feet underground, and connect the oil-producing regions with various points on the coast and with many of the principal cities of the eastern portion of the United States. Through these numerous pipe lines the oil is forced by powerful steam pumps placed at various places along the lines. It is usually crude oil that is transported in this manner, to be refined where fuel is cheap and railroads or steamship lines are convenient.

DISTILLATION AND REFINING

38. Distillation is the name given to the process of separating the various compounds of the crude oil through vaporization by means of heat, and afterwards cooling or condensing the vapors. It will be shown in Table VII that the boiling points of the various hydrocarbons, given under the heads of Liquids and Solids, vary from 86° to 699°. By carefully regulating the heat of the distilling apparatus,

called the **still**, these liquids may be boiled out one at a time, thus separating them, the vapors being collected in a special cooling apparatus, known as a **condenser**. This process of successive separation of the more volatile from the less volatile parts of a substance by vaporization is termed **fractional distillation.**

39. Order of Distillates.—The order of the **distillates**, as the products of distillation are called, is given in Table V.

TABLE V

PRODUCTS OBTAINED FROM PETROLEUM

Name	Boiling Point Degrees Fahrenheit	Specific Gravity	Density Baumé's Scale
Petroleum ether	104 to 158	.65 to .66	85 to 80
Gasoline	158 to 176	.66 to .67	80 to 78
C—petroleum—naphtha .	176 to 212	.67 to .707	78 to 68
B—petroleum—naphtha .	212 to 248	.707 to .722	68 to 64
A—petroleum—naphtha .	248 to 302	.722 to .737	64 to 60
Illuminating oil (kerosene)	302 to 572	.753 to .864	56 to 32
Lubricating oil		.864 to .96	32 to 15
Paraffin or asphalt . . .			
Coke			

The order shows how the products come over in the distilling apparatus. The first column of figures gives the highest and lowest boiling points of the various distillates. Two boiling points are given, since there are usually several hydrocarbons, each with a slightly different boiling point, mixed together in every oil put on the market. The specific gravity is the ratio of the weight of the oil to that of water. The last column is the measure of the specific gravity or density according to measurements by Baumé's hydrometer, an instrument according to which oils are usually rated in the markets. Table VI gives the specific gravities corresponding to the readings of the Baumé hydrometer.

TABLE VI

SPECIFIC GRAVITIES CORRESPONDING TO BAUMÉ'S READINGS FOR LIQUIDS LIGHTER THAN WATER

Degrees Baumé	Specific Gravity	Degrees Baumé	Specific Gravity	Degrees Baumé	Specific Gravity	Degrees Baumé	Specific Gravity	Degrees Baumé	Specific Gravity
20	.9333	38	.8333	56	.7526	70	.7000	79	.6698
22	.9210	40	.8235	58	.7446	71	.6965	80	.6666
24	.9090	42	.8139	60	.7368	72	.6931	81	.6635
26	.8974	44	.8045	62	.7290	73	.6896	82	.6604
28	.8860	46	.7954	64	.7216	74	.6863	83	.6573
30	.8750	48	.7865	66	.7142	75	.6829	84	.6542
32	.8641	50	.7777	67	.7106	76	.6796	86	.6481
34	.8536	52	.7692	68	.7070	77	.6763	88	.6422
36	.8433	54	.7608	69	.7035	78	.6730	90	.6363

40. Baumé Hydrometer.—A Baumé hydrometer is shown in Fig. 3. It consists of a glass tube, near the bottom of which are two bulbs. The lower and smaller bulb is loaded with mercury or shot, so as to cause the instrument to remain in a vertical position when placed in the liquid in the vessel *a*. The upper bulb *b* is filled with air, and its volume is such that the whole instrument is lighter than an equal volume of water.

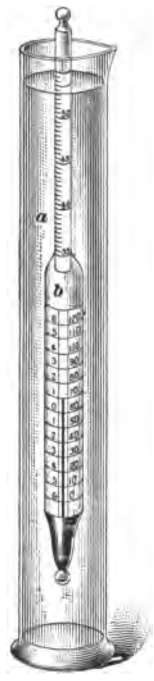

FIG. 3

The point to which the hydrometer sinks when placed in water is usually marked, the tube being graduated above and below in such a manner that the specific gravity of the liquid can be read directly. It is customary to have two instruments: one with the zero point near the top of the stem, for use in liquids heavier than water; and the other with the zero point near the bulb, for use in liquids lighter than water.

41. Refining the Distillates.—**Refining** is the final process of putting the distillates in shape for general use. As they come from the still, they are more or less colored and have a strong disagreeable odor, which becomes worse when the oils are burned. To make the oils clear and to deprive them of their offensive odor, they must be refined. This is done in large vats by means of various chemicals. After being treated the oil is of a whitish-yellow color, without disagreeable odor. In order to clarify it, the oil is run into settling tanks, where the water mixed with it settles to the bottom and the oil gradually clears. In case time is an object, the oil is filtered instead; but this latter process is not so satisfactory as the settling-tank method. The oil is now ready for barreling or shipping in tank cars to the dealers.

42. Rating Oil and Gasoline.—In selecting gasoline for any use, it is usually sufficient to know its density by

Baumé's scale, this being the rating at which it is sold in the general market. For instance, "Gasoline 72 Baumé" means that the density of the gasoline is 72° of Baumé's hydrometer. Kerosene is generally rated by its flashing point. This point is the number of degrees of temperature to which it must be heated before the vapors given off from the surface of the oil will take fire from a flame held over the containing vessel. Thus, oil of 150° test is oil that will flash or take fire when heated to a temperature of 150° F. Kerosene, at ordinary temperatures, should extinguish a lighted taper when the taper is plunged into it.

CHEMICAL CONSTITUENTS OF PETROLEUM

43. Composition of Petroleum.—Chemically, petroleum consists of what are known as *hydrocarbons*—combinations of carbon and hydrogen. Carbon is best known, in its pure state, in the form of charcoal, in which condition it is practically pure. The two substances, carbon and hydrogen—one a solid and the other a gas—combine to form gases, liquids, and solids whose physical properties—that is, density, fluidity, etc.—vary from those of hydrogen to those of carbon. This is best explained by Table VII, which shows only one series of the compounds found in the crude oil.

44. Marsh-Gas Series.—The series given in Table VII is known as the **marsh-gas series**, being so named from the lightest gas in it, marsh gas being the popular name for **methane**. It will be noticed on examination of the chemical formulas for the various products, that the number of hydrogen atoms is twice the number of carbon atoms plus 2; so that, if n is the number of carbon atoms, the number of hydrogen atoms is $2n + 2$. Thus, the general formula for the series is $C_nH_{(2n+2)}$.

45. Other Series.—There are also other series of less importance, at least eight being found in various petroleums. The marsh-gas series is an example of these, each series containing gases, liquids, and solids.

TABLE VII

COMPOUNDS IN CRUDE OIL

Name	General Formula C_nH_{2n+2}	C Per Cent.	H Per Cent.	Boiling Point Degrees Fahrenheit	Specific Gravity
Gaseous					
Methane	CH_4	75.00	25.00	gas	.559
Ethane	C_2H_6	80.00	20.00		1.036
Propane	C_3H_8	81.81	18.19		
Butane	C_4H_{10}	82.80	17.20	34	.600
Liquid					
Pentane	C_5H_{12}	83.33	16.67	86	.628
Hexane	C_6H_{14}	83.72	16.28	156	.664
Heptane	C_7H_{16}	84.00	16.00	208	.669
Octane	C_8H_{18}	84.21	15.79	257	.703
Nonane	C_9H_{20}	84.38	15.62	277	.741
Decane	$C_{10}H_{22}$	84.51	15.49	316	.757
Endecane	$C_{11}H_{24}$	84.61	15.39	360	.765
Dodecane	$C_{12}H_{26}$	84.70	15.30	386	.776
Tridecane	$C_{13}H_{28}$	84.78	15.22	420	.792
Tetradecane . . .	$C_{14}H_{30}$	84.85	15.15	462	
Pentadecane . . .	$C_{15}H_{32}$	84.90	15.10	497	
Hexadecane . . .	$C_{16}H_{34}$	84.94	15.06	536	
Octodecane . . .	$C_{18}H_{38}$	85.04	14.96		
. . . .	$C_{20}H_{42}$	85.11	14.89		
. . . .	$C_{23}H_{48}$	85.18	14.82		
. . . .	$C_{25}H_{52}$	85.23	14.77		
Solid					
Paraffin (myricyl)	$C_{27}H_{56}$	85.26	14.74		
Paraffin (ceryl) .	$C_{30}H_{62}$	85.31	14.69	699	

Beginning with the liquid pentane and going down the list, the boiling points of the various substances gradually rise. This means that at ordinary temperatures there are in the series a number of substances of consistencies varying from that of water to that of lard and wax. Advantage is taken of this fact in the separation of the many hydrocarbons in the manufacture of various oils, etc.

46. Crude Oils.—Crude oils from different localities differ considerably in the proportions of lighter oils that they

TABLE VIII

SAMPLE ANALYSIS OF PENNSYLVANIA OIL

Boiling Point Temperature Fahrenheit up to	Distillate	Specific Gravity	Per Cent.	Flashing Temperature Degrees Fahrenheit
113	Rhigolene	.59 to .625	traces	
113–140	Chymogene			
140–338	Gasoline, naphtha, and benzine	.636 to .737	16	0 to 32
338–482	Kerosene	.780 to .820	50	100 to 122
482	Lubricants	.85 to .915	15	230
	Wax		2	
	Waste		16	

contain, and also in the character of the solid constituents that remain after distillation. Most of the gasoline and naphtha used in the United States comes from the crude oil of the Western Pennsylvania and Ohio oil fields, the oil from these sections containing a much greater proportion of these constituents than the oils of California and Texas. Texas oil differs also from that of the eastern districts just mentioned, in that its principal solid constituent, known as its *base*, is asphalt; whereas the solid residue, or base, of the Pennsylvania oil is chiefly paraffin.

47. The proportions of the various constituents of oils from the three districts are given in Tables VIII and IX, according to the commercial classification. In the Pennsylvania oil, only traces of rhigolene and chymogene are found, which, when exposed, evaporate almost at once.

TABLE IX

SAMPLE ANALYSES OF TEXAS AND CALIFORNIA OILS

Texas Oil		California Oil	
Distillate	Per Cent.	Distillate	Per Cent.
Naphtha and lighter oils	10.8	Gasoline	2.8
Kerosene	54.5	Kerosene	14.4
Residue	34.7	Middlings	23.1
		Lubricants	34.1
		Asphalt	21.4
		Residue	4.2

48. In its crude state, Texas oil is comparatively thick and heavy, and is used to a large extent, without refining, as a fuel under steam boilers or in locomotives. It is also used by mixing it with certain chemicals and compressing the mixture, under pressures of from 300 to 1,000 pounds per square inch, into small lumps or bricks, called **briquets.** When thus solidified, the heat value of the mixture is double that of the same weight of bituminous coal. An average heat value for the crude Texas oil is 19,875 British thermal units per pound.

The crude oils of California, like those of Texas, have an asphalt base, but they have a larger percentage of illuminating oils and gasoline, and slight traces of paraffin are also sometimes found.

49. The relative proportions of the different compounds existing in petroleum have never been fully determined. Yet an approximate idea may be obtained by distilling

Pennsylvania petroleum and referring the results to Tables VII and X. The latter table gives the commercial products and the compounds supposed to be contained therein.

TABLE X

PRODUCTS MANUFACTURED FROM PETROLEUM

Name	Average Boiling Points Degrees Fahrenheit	Average Specific Gravity	Use
Natural gas	gas	.630 of air	Fuel and light
Rhigolene	32	.622 of water	Local anesthetic
88° gasoline	122	.640 of water	Extraction of oils; carbureted air machines
Stove gasoline	212	.710 of water	Fuel in gasoline engines and stoves
63° deodorized benzine	230	.725 of water	Varnish-makers' and painters' use
Kerosene	302	.796 of water	Illuminant
Lubricating oils		.875 to .915	Lubricants
Vaseline		.875 to .890	Vehicle for ointments, etc.
Paraffin wax		.850 to .900	Candles, insulation, etc.

50. Oxygen is shown to exist in nearly all petroleum, but much of this may be due to absorption, since all distillates are known to absorb it quite freely. Nearly all the oxygen is contained in the form of acids and phenylated compounds.

Besides carbon, hydrogen, and oxygen, nitrogen has been found in nearly all crude oils.

51. The element that has been of especial annoyance to the American refiner is sulphur. This is found in Ohio, Indiana, and Canadian oils in such quantities (up to .98 per cent.) as to give them a marked odor, which increases during distillation. Silver, copper, mercury, iron, arsenic, and even gold have been found in minute quantities in the ash of petroleum. These elements, however, seem to have but little effect on the properties of petroleum.

EXAMINATION OF OILS

52. The color of the American crude petroleum varies from a clear water white, through a straw yellow, light amber, red, deep red, dark brown, to an opaque black.

The first, although only a freak in the petroleum fields, has been found in a well at Holders Run, Armstrong County, Pennsylvania. The others are of common occurrence, and may be seen in the crude oils of West Virginia, Pennsylvania, Ohio, Indiana, California, Kentucky, Texas, and Wyoming. Each of these states has produced crude oils of various shades, the light-colored oils usually coming from some strata nearer the surface than those of a darker shade.

53. Nearly all crude oils have a fluorescence varying from blue to dark green. That of Pennsylvania is of a beautiful light grass green. The specific gravity of crude oil varies from .77 to .98, all being lighter than water. It has been found that there exists a certain connection between color and specific gravity, the lighter-colored oils usually having a lower specific gravity, and vice versa.

54. The variability mentioned in the preceding articles depends partly on the chemical composition and partly on the physical condition of the oil. All crude oils hold more or less natural gas in solution, which lowers their specific gravity; on the other hand, oils containing a comparatively large percentage of paraffin or asphalt have a greater specific gravity—this also applies to all sulphur oil. It further has been found that oils having low specific gravities furnish a greater percentage of gasolines and illuminating oils than those that are heavier.

The specific gravity of an oil plays an important part in its price. The more important factor in setting the price of oil, however, is its chemical composition and freedom from suspended matter. Heavy oils hold water and earthy matter in suspension, and must be heated in order that these may be settled before the oils are received by the pipe line. This causes a loss of the more volatile parts, and necessarily

makes the oil less valuable. The sulphur oils, besides being heavier, require a more expensive treatment, in order to produce a first-class illuminating oil, and, consequently, are not so desirable to the refiner.

When an oil contains very small percentages of gasoline and burning oil, and, in consequence, has a high fire-test and is free from sediment and wax, it may be of a much higher value as a lubricant, requiring no refining. Such oils are sold as natural lubricating oils.

55. The refiner generally attempts to produce all, or a part, of the compounds given in Table X by fractional distillation and subsequent purification with sulphuric acid, caustic soda, steam, and such other chemicals as the distillate may require.

The specific gravity being carefully taken, a given quantity of the crude oil is heated to 120° F. and poured into a graduated cylinder to settle. After standing for 10 or 12 hours, the amount and nature of the sediment is determined. Another sample of definite quantity of the crude oil is weighed and then dried for 24 hours over sticks of chloride of calcium. The difference in weight is ascribed to the loss of water, from which the percentage of water can readily be calculated.

The presence of certain offensive sulphur compounds may be detected by the odor, and they will be sure to appear in the distillates. The condition of these compounds is best determined by chemical treatment of the distillate.

COMPARISON OF GASOLINE AND KEROSENE

56. The two products of petroleum chiefly used in internal-combustion engines are kerosene and gasoline. Of these, the latter is by far the simpler to use, owing to the ease with which it may be vaporized. Commercial gasoline, as has already been pointed out, is not a homogeneous compound, but a mixture of lighter and heavier products. It is rated according to its density, common stove gasoline being usually from 71° to 72° Baumé. Owing to evaporation and

other causes the density of the gasoline as actually purchased is likely to be somewhat greater than its nominal rating, and may test as low as 68°. The vapor of gasoline that forms over the liquid consists chiefly of pentane, C_5H_{12}, having a specific gravity of .628; but the liquid gasoline consists of a mixture of hexane and heptane, the composition varying with the specific gravity of the gasoline.

A gasoline with a specific gravity of .683 and a boiling point of 154° F., has shown the following composition by analysis: hexane, 80 per cent.; heptane, 18 per cent.; pentane, 2 per cent. The chemical composition is 83.8 per cent. carbon and 16.2 per cent. hydrogen; and the chemical formula is

$$41.86C_6H_{14} + 6.48C_7H_{16} + C_5H_{12}$$

This formula will serve for use in calculating the fuel value.

Commercial gasoline evaporates very readily at ordinary temperatures, but quite slowly in cold weather, and leaves small percentages of a heavier oil, which evaporates slowly or not at all. The vapor tension varies considerably with the temperature, but at 60° F. the vapor of commercial gasoline represents about 130 volumes of the liquid and sustains a water pressure of from 6 to 8 inches. An explosive mixture of gasoline vapor and air is composed of the vapor of 1 part of liquid gasoline to from 8,000 to 10,000 parts of air by volume. The volume of the vapor will vary, but an average proportion will be 2.15 of gasoline vapor to 100 parts of air.

So far as their heating value per pound goes, there is not much to choose between kerosene and gasoline, each developing about 19,800 British thermal units per pound. Kerosene, however, is about 10 per cent. heavier, so that a gallon of kerosene has more fuel value than a gallon of gasoline.

Ordinary kerosene varies in specific gravity (at 59° F.) from .760 to .820. Exceptionally light kerosene, such as the Pennsylvania light oil, has a specific gravity below .760. The boiling point of kerosene of .760 specific gravity is

302° F. and of kerosene of .820 specific gravity 536° F. Kerosene begins to give off vapor at from 100° to 120° F., and this vapor is mainly nonane, C_9H_{20}. Liquid kerosene is a mixture of decane, $C_{10}H_{22}$, with a little hexadecane, $C_{16}H_{34}$. The boiling points of these three liquids are as follows: nonane, C_9H_{20}, 277° F.; decane, $C_{10}H_{22}$, 316° F.; hexadecane, $C_{16}H_{34}$, 536° F. Average kerosene consists chiefly of decane. For the chemical action that takes place when kerosene is burned, that corresponding to the combustion of decane may be taken, without appreciable error.

GASEOUS FUEL

NATURAL GAS

57. Occurrence.—Natural gas is usually found when boring for petroleum, although sometimes it occurrs in regions where no petroleum is found. Scarcely any oil wells are bored without finding more or less gas. It consists of the lighter hydrocarbons, usually from 75 to 97 per cent. being marsh gas. The gas is confined under great pressure in the pores of rock or sand, from which it issues at a high velocity as soon as the drill enters the deposit. From the well, the gas is piped to the point at which it is to be used. As the pressure is in many cases too high, a pressure-reducing valve is placed in the supply pipe to reduce the pressure to that desired.

Compared with coal gas, natural gas is a poorer light giver. Its heat-giving power is, however, as good as the best coal gas, and its low price makes it desirable for gas-engine purposes.

58. Composition.—It has been found that natural gas, which is now generally acknowledged to belong to the same class and have the same origin as petroleum, is composed almost entirely of methane, ethane, and propane. The first, or marsh gas, constitutes about three-fourths of all the gas

analyzed. Peckham gives the following analyses for a number of noted American gas wells:

Well	Carbon Dioxide CO_2	Carbon Monoxide CO	Hydrogen H	Methane CH_4	Ethane C_2H_6	Propane C_3H_8
Burns . .	.34	trace	6.10	75.44	18.12	trace
Leechburg	.35	.26	.56	89.65	4.39	trace
Harvey . .	.66	trace	13.50	80.11	5.72	trace

Burns's well is in the northern part, and the Harvey well is in the southern part of Butler County, while Leechburg is in Armstrong County, Pennsylvania. Nitrogen has been found in Russian natural gas from the Baku oil fields, but very little has been reported to exist in any of the Pennsylvania gases.

59. Analysis.—The following is the analysis of Findlay, Ohio, gas as made by Prof. C. C. Howard:

Constituents of Gas	Per Cent.
Marsh gas (methane, CH_4)	92.61
Olefiant gas (ethylene, C_2H_4)	.30
Hydrogen, H	2.18
Nitrogen, N	3.61
Oxygen, O	.34
Carbon dioxide, CO_2	.26
Carbon monoxide, CO	.50
Hydrogen sulphide, H_2S	.20

The calorific value of natural gas usually varies between 850 and 1,150 British thermal units per cubic foot at approximately atmospheric pressure.

COAL GAS

60. Manufacture.—**Coal gas** is gas made directly from coal. It is in general use in all the large towns and cities in civilized countries for illuminating streets and buildings. It is made by heating bituminous, or soft, coal in **retorts**, which are large, semicircular cylinders made of fireclay or cast iron. A fire is built underneath these retorts, and they

are brought to a cherry-red heat. A measured charge of coal is then put in with a long shovel, the mouth of the retort closed with a cover, and the cover sealed with cement. The coal, being heated without access to air, is changed to coke, a hard sponge-like substance, with a metallic luster, which gives forth a ringing sound when struck lightly. The remainder of the coal becomes a mixture of illuminating gas, water vapor (steam), ammonia, sulphur compounds, and tar. As the illuminating gas is the only portion that must be sent through the gas pipe, it becomes necessary to remove the other substances mixed with it. The gas is drawn from the retorts by means of a pump, or exhauster.

61. Composition of Coal Gas.—Coal gas is a mixture of various organic and inorganic compounds, the amounts of which in a given volume of gas vary somewhat, according to the kind of coal used and the temperature at which it is carbonized. The following may be considered the average composition of purified coal gas, from which the carbon dioxide has not been removed:

Constituents of Gas	Per Cent.
Hydrocarbon vapors	.6
Heavy hydrocarbons	4.4
Carbon dioxide	3.4
Carbon monoxide	10.1
Marsh gas	30.6
Oxygen	.3
Hydrogen	45.9
Nitrogen	4.7
Total	100.0

In the unpurified state, coal gas also contains ammonia, hydrogen sulphide (H_2S), and a small percentage of other compounds, among which carbon disulphide (CS_2) predominates. Of the impurities, ammonia and hydrogen sulphide are carefully removed, but no extra efforts are made to remove the small amount of carbon disulphide that might escape the washer.

62. Specific Gravity, Thermal Value, and Odor of Coal Gas.—Ordinary coal gas has a specific gravity of

about .45, air being taken as unity. It yields from about 650 to 725 British thermal units per cubic foot. The well-known pungent odor of coal gas is due mainly to the **olefiant gas,** composed of what are known as the heavy hydrocarbons.

WATER GAS

63. Composition.—**Water gas** is a mixture of hydrogen and carbon monoxide. It is made commercially by the contact of steam with incandescent carbon in the form of anthracite or coke. The steam is decomposed, the hydrogen being separated from the oxygen. The oxygen takes up carbon from the coal or coke and forms carbon monoxide, along with a small amount of carbon dioxide. The resultant gases from the contact of steam with incandescent carbon are then mainly hydrogen and carbon monoxide, chemically separate but mechanically mixed together. This is what is called **blue, or uncarbureted,** water gas. It burns with a flame that gives little light, and is consequently useless for lighting purposes except in incandescent lamps of the Welsbach type. In actual practice, this water gas is always enriched with oil gas, which furnishes the hydrocarbons necessary to make a luminous flame. In many of the older forms of apparatus, the oil gas was made separately, but it is now commonly produced in the same machine as that in which the water gas is made.

64. Analysis.—The following is a volumetric analysis of a sample of purified water gas:

Constituents of Gas	Per Cent.
Hydrocarbon vapors	1.2
Carbon dioxide	3.0
Heavy hydrocarbons	12.6
Oxygen	.4
Carbon monoxide	28.0
Hydrogen	31.4
Methane	20.2
Nitrogen	3.2
Total	100.0

65. Coal and Oil Required.—Water gas requires from 30 to 40 pounds of coal or coke per 1,000 cubic feet of gas made, and from 4 to 5 gallons of oil, depending on the candlepower required. Usually between 5 and 6 candlepower is obtained from each gallon of oil used per 1,000 cubic feet. There are about 300 heat units yielded per cubic foot of uncarbureted water gas, and about 675 heat units are yielded by 24-candlepower carbureted water gas. The specific gravity of 24-candlepower water gas is about .625, air being taken as unity.

Pure uncarbureted gas has no perceptible odor, but the carbureted gas has an odor fully as strong as coal gas. This is mainly due to the hydrocarbons from the oil that is used for enriching.

66. Water-Gas Machines.—Almost all the **water-gas machines** now in use are modifications of the Lowe type. The **Lowe type** of machine consists of a *generator*, where the blue water gas is produced, and a *superheater*, or a *carbureter* and a superheater, where the oil is vaporized and mixed with the blue water gas. The generator is a circular steel shell, the height of which is about $1\frac{1}{2}$ times the diameter. It is lined with a double lining of firebrick blocks, and is provided with grate bars at the lower end and with air-tight doors at the top, where the coal is charged in, and at the bottom, where the clinkers are taken out. There are also connections for the escape of the gas and for the proper supply of steam and air. The capacity of any generator depends largely on the grate area, and may be figured at a minimum of 20,000 cubic feet of gas per square foot of grate surface per 24 hours.

ARCHER GAS

67. Archer gas is water gas made from crude petroleum by a continuous process; it derives its name from the inventor of the apparatus. The oil is pumped in a small stream into a red-hot retort, where it is quickly reduced to vapor by the heat. The oil vapor is then mixed with a current of superheated

steam, and the mixture is driven through a long coil of very hot pipe. The oxygen of the steam unites with the carbon of the oil, forming carbon monoxide, and the hydrogen is set free. The resulting gas is permanent, and is of high value for heating purposes. It is produced at a pressure of 8 to 10 pounds per square inch.

OIL GAS

68. Oil gas is made, in much the same manner as coal gas, by the process known as destructive distillation. This process consists in heating the oil to a very high temperature and causing the heavy hydrocarbons it contains to break up into the lighter or gaseous forms. In the manufacture of this gas, not only is petroleum utilized, but also many animal and vegetable fats and oils; among these are to be found the waste fats that occur in the manufacture of woolens, and ordinary rosin.

PRODUCER GAS

69. Manufacture.—Producer gas, as the term is usually applied in the United States, is a sort of diluted water gas not enriched with illuminating oils. The gas is made by a continuous process in what is known as a producer. There are two types of producers, known as **suction producers** and **pressure producers.** The former type has the advantage of simplicity, and for this reason is generally preferred for all but the largest engines. The movement of the gases and steam in the producer is induced by the suction of the engine itself, so that the gas is produced automatically in exact proportion to the demands of the engine. Its only drawback is the fact that the necessity of pumping the air and gas through so extended an apparatus slightly reduces the effective power of the engine, since the charge cannot be taken in at atmospheric pressure. This drawback is avoided in pressure producers, in which a blower is used to maintain the pressure of the gases in the generator at or slightly above that of the atmosphere.

70. In general, the process of generating gas by means of producers consists in passing air, or a mixture of air and steam, through a bed of burning coal, coke, charcoal, or wood contained in a suitable receptacle known as a **generator.** The combustion of this fuel taking place in the lower part of the producer generates carbon dioxide, the greater percentage of which, in traveling up through the bed of highly heated carbon, is decomposed, one unit of the oxygen of the carbon dioxide uniting with a unit of carbon to form carbon monoxide. The steam entering the producer with the air is decomposed by the high temperatures into hydrogen and oxygen, the former passing through as free hydrogen, while the latter unites with the carbon just as does free oxygen from the air.

71. The formation of carbon dioxide from carbon and oxygen evolves heat, and that portion of the fuel bed where this takes place will be hottest. The two operations of decomposing steam and reducing carbon dioxide to carbon monoxide, however, absorb heat, so that the combined result of the three operations tends to effect a temperature balance more or less controllable through variation of the amounts of steam supplied.

72. If the fuel beds contain holes, then air, composed of free oxygen and the inert element nitrogen, will pass through the producer and affect the final composition of the gas. The resulting gas will then contain carbon monoxide, carbon dioxide, free hydrogen, small percentages of illuminants, and nitrogen.

73. Description of Gas Producer.—The following explanation of the Koerting producer applies in most particulars to all of its kind. The apparatus is shown, somewhat simplified, in Fig. 4. The plant consists essentially of a generator *a*, an evaporator *b*, a scrubber or purifier *c*, and a sawdust purifier *d*. The generator is simply a vertical steel shell, cylindrical in form, and lined with firebrick. It is fitted at the bottom with grates *e*, and when in operation is kept nearly full of fuel. At the top is a hopper *f* having an air

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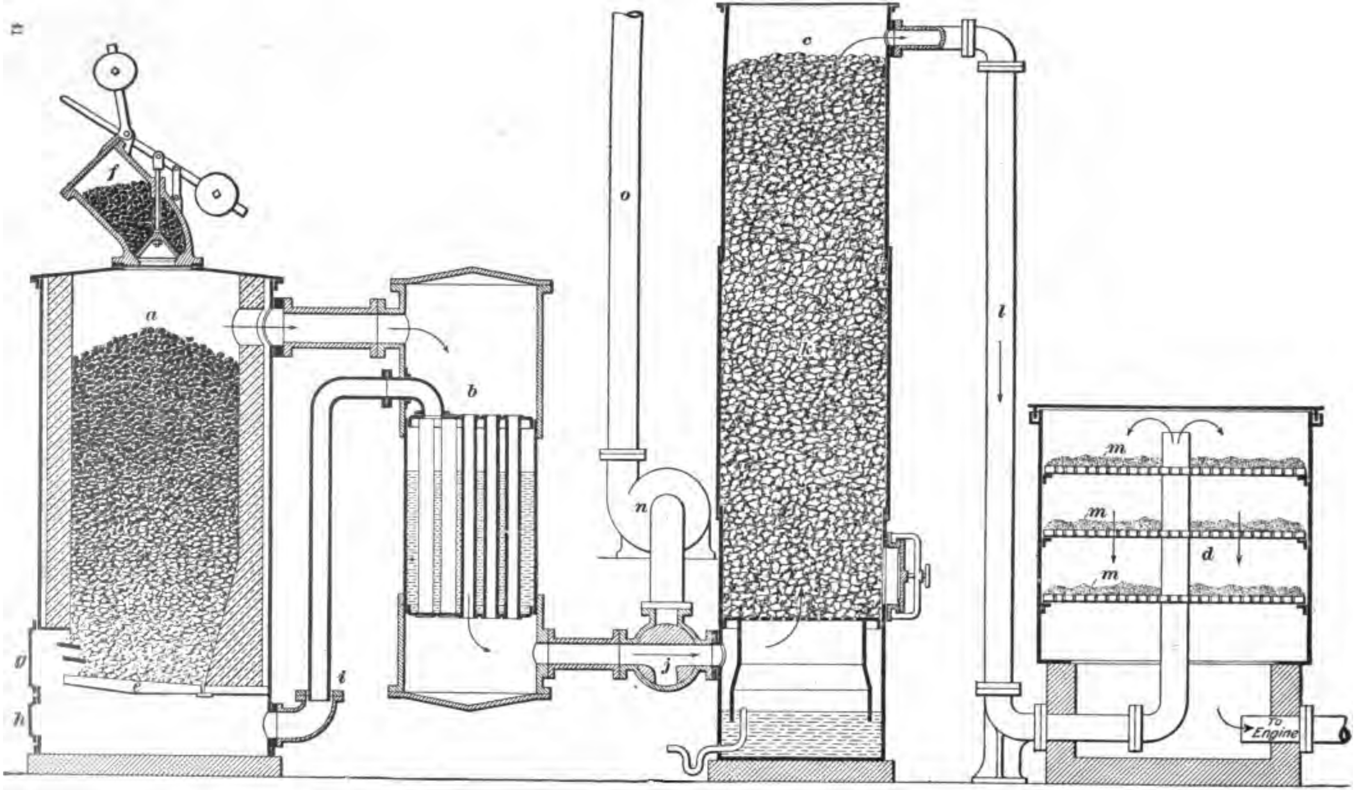


FIG. 4

lock, through which the fuel, preferably pea-sized anthracite or coke, is fed to the fire. An air lock is necessary to prevent the air from entering while the fuel is being introduced. At the bottom of the generator is a fire-door *g* for working the fire, and an ash door *h* for removing ashes. The ash-pit has a water seal, to prevent the escape of gas or the entrance of air. At each charging stroke of the engine, a quantity of gas is sucked out of the generator and passes through the evaporator *b*. This device performs the double function of generating steam and cooling the gases, and resembles in form a small tubular boiler. The gases, in passing down through the tubes of this boiler or evaporator, give up part of their heat to the water that surrounds the tubes, furnishing sufficient steam to supply the generator *a*. The water first passes through the water-jacket of the engine, where it takes up considerable heat, so that it is readily changed to steam, in the evaporator. As the steam passes to the generator, it draws a definite amount of air with it around the inlet pipe at *i*, and thus supplies the oxygen necessary for the partial combustion of sufficient coal to maintain the necessary temperatures in the generator. By this arrangement, it is obvious that the heat taken from the hot gas on its way to the engine, as well as that taken from the heated cylinder walls, is returned to the generator in the steam and air with which it is supplied.

74. The gases generated from ordinary fuels, especially from soft coal, are not fit to be used directly in the cylinder of an engine, because of entrained impurities. The amount and nature of these impurities vary widely with the kind of fuel used. The impurities to be removed from the gas generated from a ton of fuel are, for anthracite, from 1 to 2 pounds of ammonia, traces of sulphur, and from 5 to 10 pounds of tar, and for bituminous coal, from 4 to 5 pounds of ammonia, sulphur varying from traces to 5 per cent., and from 10 to 12 gallons of tar.

75. In the case of suction-producer plants using anthracite and carbonized fuels, such as charcoal and coke, the

purifying process requires only a washer or scrubber. From the evaporator, the cooled gas passes through a vent valve *j* into the bottom of the scrubber *c*, and up through a bed of coke *k*, over which water is sprayed continuously. While passing through this wet coke, the gas is further cooled and cleansed of any fine ash or foreign matter it may have carried over from the generator. The gas leaving the scrubber descends through a vertical pipe *l* and enters the sawdust purifier *d*, within which it rises to the top through a short vertical pipe, and thence filters down through several layers *m*, *m* of sawdust supported on wooden gratings. The size of this purifier cylinder is such as to allow the gas to travel very slowly, and any impurities, such as tar, moisture, and dust, not extracted in the scrubber are caught in the sawdust beds. The comparatively large volume of the purifier, which serves as a receiver, reduces the pulsating effect due to the engine and makes the suction at the generator practically constant.

76. The plant is started by first building a fire on the grate of the generator, and charging it with coke or coal, the chimney pipe being open and the engine gas pipe closed. Air is drawn through the generator by means of a small hand blower *n* until the charge is well ignited, the vent valve *j* being turned so that the smoke will escape to the atmosphere through the pipe *o*.

The fuel having become incandescent up to the bottom of the hopper, the passage to the chimney is closed and the gas is tested by igniting a small jet from a test cock. If the gas burns with a reddish-blue flame not easily extinguished, the valve leading to the engine may be opened and the engine started. As soon as the engine has made a few revolutions it will pump its own gas. The coal is fed to the hopper every half-hour or hour, depending on the size of the plant.

77. When the plant is to be shut down, the generator is filled with coal and the vent valve to the chimney opened to admit just enough air to maintain a fire. Opening the vent valve to the chimney closes communication with the scrubber,

and the gas that the scrubber contains can be used when the engine is again started.

Producer plants consume only a very small amount of coal while the engine is shut down, and can be put in operation at full capacity in a very few minutes, on account of the heavy bed of burning coal carried at all times.

78. The chemical actions involved in generating gas are practically the same for both the suction and the pressure producer, the essential difference between the two types being in their mode of operation. In the former case, the gas is sucked from the generating apparatus by the action of the engine itself; and in the latter case, steam and air are forced into the producer by a pressure blower using steam from a small auxiliary boiler. This blower supplies the power necessary to overcome the resistance encountered by the gas in passing through the generator and the cleaning apparatus on its way to the gasometer, and also introduces the steam.

79. While, as yet, anthracite is the only fuel that has proved entirely satisfactory in the suction producer, almost any fuel containing carbon and volatile hydrocarbons can be employed in the pressure producer, and any of the gases capable of forming a combustible mixture with air can be employed for generating power in a properly designed gas engine. For plants of over 75 or 100 horsepower, pressure producers are sometimes used.

TABLE XI

AVERAGE ANALYSIS OF PRODUCER GAS

Constituents	Gas From Bituminous Coal	Gas From Anthracite
Nitrogen, N	56.5	57.3
Carbon monoxide, CO	27.0	27.0
Hydrogen, H	12.0	12.0
Carbon dioxide, CO_2 .	2.0	2.5
Methane, CH_4	2.5	1.2

80. Composition of Producer Gas.—The composition of producer gas is indicated in Table XI, which gives the average percentage, by volume, of the various constituents of producer gas made from bituminous and anthracite coal.

81. Calorific Value of Producer Gas.—Producer gas has a calorific value of from 110 to 160 British thermal units per cubic foot. About 80 cubic feet of gas should be produced per pound of coal.

BLAST-FURNACE GAS

82. Carbon Monoxide.—In the reduction of iron ore, it is necessary to use a considerably greater quantity of coke than the oxygen supplied by the blast will consume, in order to prevent the oxidation of the iron. The result is that a large proportion of the gas from the stack is not carbon dioxide, CO_2, but carbon monoxide, CO. Ordinarily, this gas goes to waste at the top of the stack, burning with the familiar blue flame.

83. Use of Blast-Furnace Gas.—Although blast-furnace gas is very poor in heating value, having only about 100 British thermal units per cubic foot, or two-thirds as much as good producer gas, it has been found possible to utilize it in large engines. To accomplish this, the gas is led through a series of scrubbers to purify it and settle the dust, and is then supplied to the engine in much the same manner as is producer gas, except that the proportion of gas to air must be larger. The composition of average blast-furnace gas is shown in Table XIII, from which it will be seen that only about 30 per cent. of the gas is combustible, the remaining 70 per cent. being nitrogen and carbon dioxide.

84. A calculation of the heating values of the carbon, the limestone flux, and the coal shows that the gas produced in the course of smelting a ton of pig iron represents over 13,000,000 British thermal units, of which 25 per cent. can be utilized in an engine of average efficiency. This would be equivalent to about 1,000 available horsepower per ton of

iron produced per hour, and it is evident that every blast furnace produces an enormous amount of power that might profitably be utilized.

85. Tables of Heat Values.—Following are given two tables of heat values, which will be useful in comparing the values of various gases for gas-engine purposes.

TABLE XII

HEAT VALUES

Gases, Vapors, and Other Combustibles	Heat Units per Pound	Heat Units per Cubic Foot	Foot-Pounds of Work, per Cubic Foot
Crude petroleum, West Virginia, Sp. Gr. .873 . . .	18,324		
Light petroleum, Pennsylvania, Sp. Gr. .816 . .	17,933		
Benzine, ...	18,448		
Gasoline	19,800		
Water gas, American . .		185	143,930
Gasoline vapor	19,800	1,240	966,472
Natural gas, Leechburg, Pa.		1,051	817,678
Natural gas, Pittsburg, Pa.		892	770,976
Ethyl alcohol	28,500		

ALCOHOL

86. Alcohol as a Fuel.—In the past alcohol has not been used in the United States as a motor fuel on account of the high internal-revenue tax imposed on it. This tax having been removed, its use will no doubt soon become quite common. In other countries, particularly in Germany, it has become an important engine fuel, and is used also for heating, and, with incandescent mantles, for lighting. For such use, it is **denatured**, or rendered unfit for drinking, by the addition of poisonous ingredients, such as wood alcohol, some other hydrocarbon distilled from petroleum, and sometimes coloring matter.

TABLE XIII

CHARACTERISTICS OF POWER GASES

	H	CO	CH_4	C_2H_4	O	CO_2	N	Cubic Feet of Air per Cubic Foot of Gas	Gas B. T. U. per Cubic Foot		Mixture B. T. U. per Cubic Foot	
									High	Low	High	Low
Common coal gas	39.78	7.04	45.16	6.38	.06	1.08	.50	6.38	727	651	98.5	83.1
Carbureted water gas . . .	21.8	28.1	30.7	12.9	.5	3.8	2.2	6.00	702	635	100.3	90.7
Uncarbureted water gas . .	49.50	35.93	1.05			4.25	8.7	2.10	295	265	92.2	82.8
Producer gas, little steam .	9.2	25.3	3.1	.8		3.4	58.2	1.24	160	150	75.0	67.0
Loomis-Pettibone coal gas .	14.0	20.0	2.0	.20	.10	8.2	55.5					
Dowson gas, average . . .	18.0	25.0	3.0			7.0	47.0	1.32	119	115	51.4	49.6
Mond gas	29.0	12.0	2.0			14.5	42.5	1.17	156	139	71.9	64.0
Coke-oven gas	53.0	6.0	35.0	2.0		2.0	2.0	5.06	620	524	102.3	86.4
Blast-furnace gas	3.0	27.5				10.0	59.4	.81	100	90	55.3	54.8
Oil gas	5.6	8.9	54.9	28.9		.9		9.78	1,085	994	100.7	92.2

PRINCIPLES OF THE GAS ENGINE

THEORY OF OPERATION

WORK IN ENGINE CYLINDER

DEFINITIONS

1. The **internal-combustion engine,** of which all gas, gasoline, and oil engines are types, is a machine by means of which the heat of combustion of the fuel used may be transformed into work by the direct action of the products of combustion on the moving parts of the machine. Combustion takes place directly in the engine cylinder, and for this reason engines of this class are broadly termed internal-combustion engines. The term **explosion engine** is also often applied to this class of engine, since the combustion is so rapid that it resembles an explosion.

2. In the internal-combustion engine, the burning of the fuel results in gases of high temperature and pressure, which act directly on a piston, and by their expansion overcome the resistance of the piston, causing it to move, and thereby perform work. In gas-engine practice, this work is done on a piston that moves back and forth in a cylinder to which the air and fuel are admitted and from which the burned gases are discharged by means of suitable valves. In some forms of engines, work is done on one side of the piston only;

such engines are known as **single-acting engines.** In other forms work is done on both sides of the piston, and these are known as **double-acting engines.**

3. The construction of the single-acting engine is illustrated in Fig. 1, in which *a* is the cylinder; *b*, the piston;

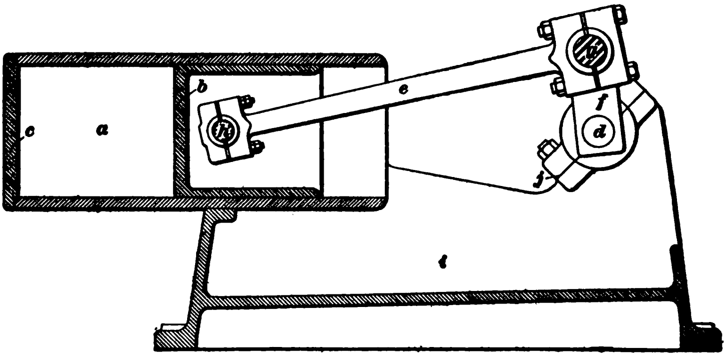


FIG. 1

c, the cylinder head; and *d*, the rotating shaft, known as the *main*, or *crank-shaft.* In order to convert the to-and-fro, or reciprocating, motion of the piston into a rotary motion of the crank, a connecting-rod *e* and a crank *f* are used. The connecting-rod is attached to the crank by means of the pin *g*, called the *crankpin*, and to the piston by means of the pin *h*, called the *piston pin*, or *wristpin.* The frame *i* supports the cylinder *a* and the main-shaft bearing *j*, and forms the rigid connection between them.

4. The construction of the double-acting engine is shown in Fig. 2, corresponding parts being represented by the same

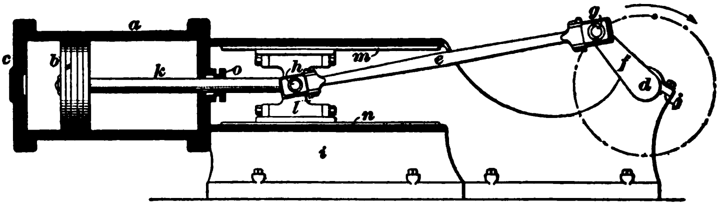


FIG. 2

letters as those used in Fig. 1. It will be seen that the principal points of difference between these two constructions are

that, in Fig. 2, the cylinder is closed at the end toward the crank and a piston rod *k* transmits the motion of the piston to a crosshead *l*. The pin *h*, which connects the crosshead to the connecting-rod, is called a *crosshead pin*, or *wristpin*. The crosshead is kept in alinement with the cylinder by guides *m* and *n*. Leakage about the piston rod is prevented by a stuffingbox *o*.

5. The end of the cylinder nearest the crank is called the *crank end*, while the other end is called the *head end*. The movement of the piston from the head end to the crank end is called the *forward*, or *outward*, *stroke;* the movement in the opposite direction is called the *return*, or *inward*, *stroke*. When the crank moves through the upper half of its revolution while the piston moves from the head end to the crank end, as shown, the engine is said to **run over**; and when the crank moves through the lower half of its revolution when the piston moves from the head end to the crank end, it is said to **run under**.

The valves that admit the new charge of air and fuel to the cylinder are called *inlet*, or *admission*, *valves*, and those which permit the burned gases to escape are called *exhaust valves*. These will be described later.

6. A **gas engine** is a type of internal-combustion engine using combustible gas as a fuel. With a few unimportant exceptions, all gas engines have been of the reciprocating type, that is, with a cylinder, and a piston that moves in a straight line. The term *gas engine* is also frequently applied to all internal-combustion engines, since in all cases the fuel must take the form of a gas either before or after it enters the engine.

7. A **gasoline engine** is a type of internal-combustion engine using gasoline as a fuel. The gasoline engine differs but little from the gas engine in its main features, the principal difference being the addition of a device, commonly called a *carbureter*, for vaporizing the fuel before it enters the cylinder.

8. An **oil engine** is a form of internal-combustion engine especially adapted to the use of kerosene and the heavier petroleum products. The oil engine differs from the gas engine in some particulars that will be explained later.

9. An **alcohol engine** is one especially adapted for using alcohol as fuel, differing from the gasoline engine chiefly in the means whereby the fuel is gasified.

10. The **charge** is a mixture of fuel and air taken in at one stroke of the engine. It varies according to the conditions of operation, and may sometimes be sufficient to fill the cylinder completely at atmospheric pressure, while at other times it may be reduced. The proportions of gas and air may also vary from time to time.

FIG. 3

11. The **exhaust gases**—sometimes called the **exhaust**—are the waste products of combustion that are expelled from the engine after having performed the work required of it.

12. The **compression space** is a portion of the cylinder into which the piston does not enter, and into which the charge is compressed previous to ignition. It is sometimes called the **clearance, or combustion, space.**

CONVERSION OF HEAT INTO WORK

13. It has been shown that heat may be made to do work by being applied to the outside of a cylinder containing a gas such as air, as shown in Fig. 3. If, instead of heating the confined gas by means of a flame on the outside of a cylinder, a stream of some combustible gas is introduced, as in Fig. 4, through a hole in the bottom of the cylinder, allowing it to burn as it enters, a large amount of heat

wasted in the first method is saved. The gas will continue to burn until the oxygen in the air contained in the cylinder is exhausted, the heated gases expanding and performing work as in the first case. The method illustrated in Fig. 4 has a still further advantage. The contents of the cylinder are heated much more rapidly, and a larger amount of work can be done in a given time.

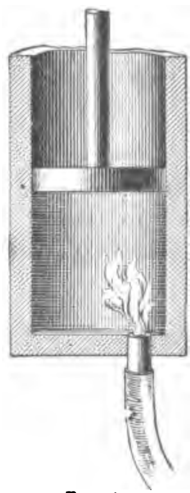


FIG. 4

14. Instead of allowing the gas to burn as it enters the cylinder suppose that the latter is filled with an explosive mixture of gas and air and that the mixture is ignited, or fired, by an electric spark at *g*, Fig. 5. The mixture explodes and the resulting pressure performs work on the piston. A much more rapid expansion is produced by this means than by the methods already mentioned. By employing a long cylinder, a greater proportion of the heat may be transformed into work, since the gases cannot escape until the pressure is very low.

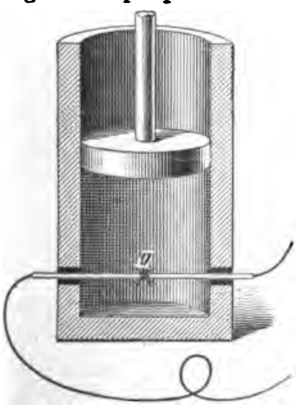


FIG. 5

15. A still further improvement is made by filling the cylinder in Fig. 5 with an explosive mixture and compressing it before ignition or firing. Suppose the cylinder to be filled with a mixture of gas and air, and the piston then forced down until the mixture is compressed into a space of, say, one-third of its former volume, and ignited by means of the electric spark. The explosion pressure is much higher than if there had been no compression, and the average pressure during the motion of the piston will also be much higher, and consequently more power can be obtained from

the gas. Since the temperature of the gas rises during compression, much of the work of compression is stored as heat and is given up again in the form of work during expansion.

16. Since heat is produced by the compression of a gas, it is easy to see that, if the compression is carried far enough, almost any desired temperature may be obtained. If the cylinder in Fig. 4 is filled with air, the air may be compressed until the temperature reaches a point equal to that which would be produced by the combustion of the gas. Then, if compressed gas is admitted through the tube in the end of the cylinder it will be ignited by the hot air, the gas burning slowly as it enters and keeping the temperature of the cylinder at the temperature of combustion, or that produced by the compression of the air. By this series of operations, a high initial pressure is obtained without an explosion. The initial pressure is much higher in this case than that obtained by the method described in Art. **15,** and because of the high temperature every particle of the fuel is completely consumed.

17. In the internal-combustion engine, or gas engine, as it is generally called, the heat energy of the fuel is converted into mechanical work by raising the temperature, and therefore the pressure, of the gas and air by combustion, and doing work by expanding the gas. The same result might theoretically be produced by simply heating pure air. In fact, this is done in the hot-air engine, which is much used for small pumping outfits. Such a process, however, has the practical objection that it takes some time to heat a body of air, owing to the fact that air is heated by contact with a hot surface only. To heat a gas by combustion requires only enough time for the flame to spread through the mixture.

18. The rise in temperature produced by the combustion of a gas is quite great, often amounting to as much as 2,500° F. If the volume of gas remains constant, the

pressure is proportional to the absolute temperature; and, if the mixture of gas and air at atmospheric pressure and temperature is burned, the pressure resulting from this heating might be four or five times as great as atmospheric pressure.

19. If the products of combustion could be stored at the temperature of the flame, and if it were practicable to deliver them to an engine in this condition, it would be possible to burn the gases in a separate chamber and deliver the hot compressed gases to the engine as they are used. There are two reasons why this cannot be done. In the first place, the extremely high temperature of the gases would destroy any valve or other apparatus controlling their admission to and exhaust from the cylinder, and would burn any lubricating oil that could be fed to the piston. The other reason is

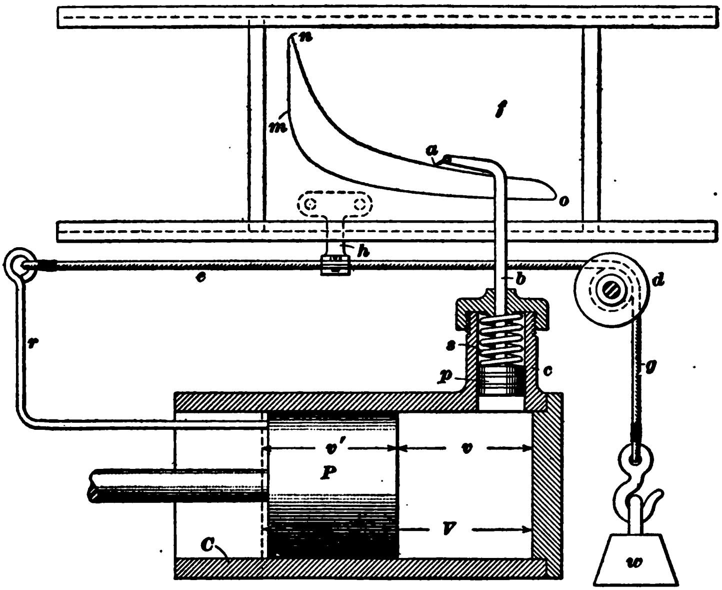


Fig. 6

that it has been found necessary to compress the gases before igniting them in order to use them most economically, and a separate machine of the dimensions required for compressing the gases would consume so much power that

the arrangement would not be economical. For these reasons, all gas engines are arranged to receive their fuel charges a cylinderful at a time, and to ignite, burn, expand, and reject each charge before receiving the next.

20. Representation of Work in a Gas Engine.—In order that what takes place in the cylinder of a gas engine may be better understood, the various processes will be explained with the aid of the pressure-volume diagram as produced by an instrument called an *indicator*. Fig. 6 illustrates the principle on which this diagram is obtained. Suppose that *P* is the plunger of a pump or the piston of an engine, working in a cylinder *C*. In the operation of any engine, there is a more or less constantly varying pressure in the cylinder, and in order to study what takes place within the cylinder it is necessary to provide some instrument that will automatically record the pressure at all points in the movement of the piston. This may be done by means of the indicator, of which it is necessary at present to study only the elementary form shown in the figure.

21. Let the small cylinder *c* be connected with the interior of the large or working cylinder *C*. In *c* is a small piston *p* to which is attached a spring *s*. Attached to *p*, also, is a rod *b* carrying at its upper end a pencil *a*. At *f* is a slide, attached by the arm *h* and cord *e* to the arm *r*, which is fastened to the working piston *P*. Running in the opposite direction from the slide is a cord *g* passing over a pulley *d* and having at its end a weight *w*.

It will be seen that, as the piston moves back and forth during the operation of the engine, it will carry with it the slide *f*. As the pressure changes within the cylinder *C*, it also changes in cylinder *c*; hence, the piston *p* moves up or down as the pressure rises or falls. Therefore, the point of the pencil *a* will be in a position that, measured from left to right, corresponds to the position of the piston *P*, in the cylinder, measured from right to left, and the height of the pencil corresponds to the pressure within the cylinder *C*. As the area of the end of the piston does not change, and since

the volume of a cylinder is equal to the product of its area and its length, any movement of the piston P toward the left will give a corresponding increase in volume. Suppose that the area of the piston is 1 square foot, and that the distance v between the piston and the cylinder head is 1 foot, then the volume in front of the piston is 1 cubic foot. Suppose that the piston were to move a distance of v' to the left. Then, if v' equals 1 foot, the distance V between the face of the piston and the end of the cylinder would be 2 feet, and the volume contained in the cylinder in front of the piston would be 2 cubic feet. Similarly, when the piston is at a distance of $1\frac{1}{2}$ feet from the end of the cylinder, the volume will be $1\frac{1}{2}$ cubic feet. Hence, the position of the pencil, measured from left to right, corresponds to the volume of the cylinder. If a piece of paper is attached to the slide f, the pencil will draw on it a continuous line, any point on which will indicate the pressure within the cylinder corresponding to a certain position of the piston and will also correspond to a certain volume in the cylinder.

22. In the diagram shown on the slide in Fig. 6, the line drawn by the pencil shows a rise of pressure from m to n while the piston P is practically stationary. This is followed by a gradual fall of pressure from n to o while the piston is moving from right to left. On the return of the piston the pencil draws the line $o\,m$, its position indicating a lower series of pressures than when the piston is moving toward the left, and the gradual rise of the pencil line shows that the pressure is rising gradually as the piston approaches the head end of the cylinder.

23. Fig. 7 shows the diagram of Fig. 6 drawn to a larger scale. In a diagram of this kind, the horizontal position of any point on that diagram is measured from a vertical line, as $O\,P$, Fig. 7, called the *axis of pressures*. The vertical position of a point is measured from a horizontal line as $O\,V$, known as the *axis of volumes*. The horizontal distance of any point from the axis $O\,P$ is known as the *abscissa* of that point, and the vertical distance of any point from the

axis $O\,V$ is known as the *ordinate* of that point. These names are also given to the lines that measure the distances of the point from the axes $O\,P$ and $O\,V$. For instance, the distance from any point to the axis $O\,P$ and parallel to the

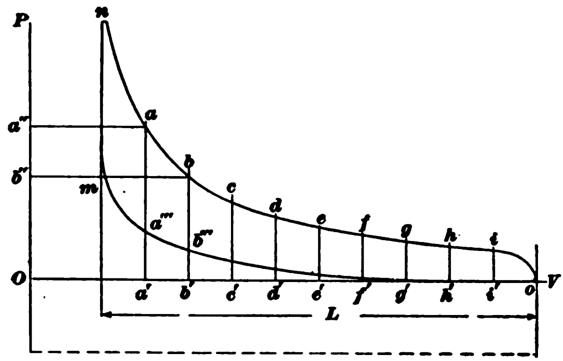


FIG. 7

axis $O\,V$ is known as the abscissa, and the distance from the axis $O\,V$ to the point and parallel to the axis $O\,P$ is known as the ordinate.

24. In the pressure-volume diagram as used for the gas engine, the axis $O\,P$, representing zero volume, may be located at the extreme position of the piston toward the head end of the cylinder. Since horizontal distances parallel to $O\,V$ represent volumes, it is sometimes convenient to locate the axis $O\,P$ at a distance from the end of the diagram that will represent the clearance volume to the same scale that L represents the volume of the cylinder. The axis $O\,V$ may represent either the pressure of the atmosphere or the line of no pressure, that is, absolute vacuum. The pressure of the atmosphere is that usually employed for the axis $O\,V$. Taking any point, as a, Fig. 7, the ordinate of the point is the distance $a'\,a$ and the abscissa of the point is the distance $a''\,a$. Similarly, the ordinate and abscissa of the point b are $b'\,b$ and $b''\,b$, respectively.

25. If the curve $n\,o$, Figs. 6 and 7, represents the expansion of a gas, as the burned gases in a gas engine, it is plain that the pressure will drive the piston from right to left,

that is, away from the head end of the cylinder. This pressure is used in an engine to overcome resistance, and as the piston moves forwards work is done. The amount of work done is represented by the total average pressure multiplied by the distance through which the piston moves. When the piston is moving away from the head of the cylinder, work, therefore, is being done on the piston by the pressure of the gas within the cylinder, the pressure being represented by the curve $n\,o$, and the average height of the ordinates $a'\,a$, $b'\,b$, $c'\,c$, etc., represents the average pressure on the piston during its expansion stroke. If the piston did not return, the work would be represented by this average pressure during the expansion stroke multiplied by the length of the stroke. In returning, however, the piston is usually called on to compress a certain amount of gas and therefore does work on the gas. This work must therefore be subtracted from that done on the piston by the gas during expansion.

26. The pressure during the return, or compression, stroke is represented by the line $o\,m$. This work performed by the piston is known as **negative work.** The average pressure during the performance of this negative work must therefore be subtracted from the average pressure during the performance of work on the piston, that is, during the performance of **positive work.** This subtraction is most easily accomplished by taking the average of the ordinates between the two curves $o\,m$ and $n\,o$, which is the same as subtracting the ordinates of those points on the lower curve from those directly above them on the upper curve. For example, the *effective pressure* at the point a is determined by either subtracting the ordinate $a'\,a'''$ from the ordinate $a'\,a$, or by measuring directly the ordinate $a'''\,a$. The ordinate representing the average height of the diagram is called the **mean ordinate,** and the pressure represented by the mean ordinate is known as the **mean effective pressure,** usually represented by the letters M. E. P.

27. The mean ordinate is obtained in practice by dividing the area enclosed by the diagram by the length L, Fig. 7.

The area is therefore the mean ordinate multiplied by the length L. Hence, since the mean ordinate represents the mean pressure, and the length of the diagram represents the distance traversed by the piston, the work done on the piston is represented by the area of the diagram. This may also be stated as follows: *In any pressure engine, the work performed on the piston is directly proportional to the area of the indicator diagram.* It is evident that, since the area of the diagram represents work, its area may be expressed in foot-pounds of work.

FOUR-CYCLE ENGINE

PRINCIPLES OF OPERATION

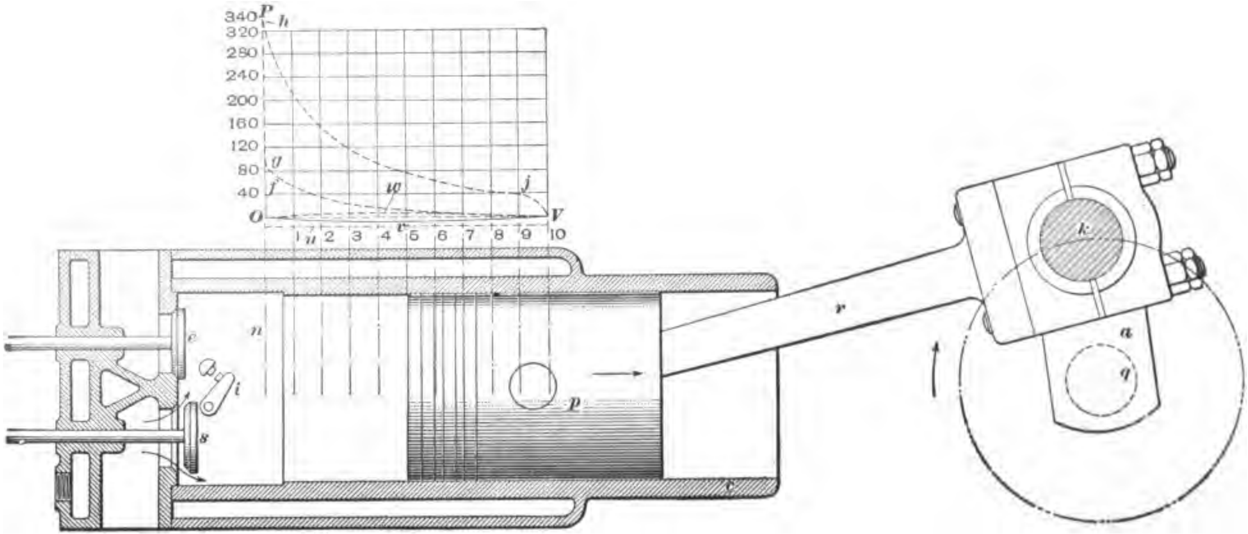
28. Definitions of Cycles.—The series of operations that produces a complete indicator diagram, as shown in Fig. 6, so that the indicator pencil returns to the starting point, is known as a **cycle.** In some gas engines, the complete cycle is produced by four strokes of the piston, or two revolutions, and these are known as **four-stroke cycle,** or simply **four-cycle engines.** In other engines, the cycle is produced by two strokes of the piston, and these are known as **two-stroke cycle, or two-cycle, engines.** The cycle is generally considered as beginning at the commencement of the suction stroke, that is, the stroke on which the fuel and air are taken into the cylinder, and to end just before the next suction stroke begins.

29. Development of Four-Cycle Principle.—In the first successful gas engine, the charge drawn into the cylinder under atmospheric pressure during part of the outward stroke was ignited when the piston had traversed about four-tenths of its stroke, the sudden rise in pressure due to the explosion of the gas being utilized to drive the piston to the end of its stroke, work being performed during the expansion of the hot gases. During the return stroke, the burned gases were driven from one end of the cylinder while a fresh charge was drawn in and ignited at the other end,

the engine being of the double-acting type. Because of the extreme wastefulness of this engine, which was of the two-cycle type, a French scientist, Beau de Rochas, in 1870, proposed a new cycle of operations. This cycle was adopted and put into practical use by Herr Otto, a German, who built his first compression engine in 1876. From this latter circumstance, the cycle came to be known as the *Otto cycle*, although the honor of its invention belongs unquestionably to Beau de Rochas.

30. Application of Four-Cycle Principle.—In the four-cycle engine, the first outward stroke is the **suction stroke,** the gas being driven into the cylinder by the pressure of the atmosphere or other pressure, because of the partial vacuum produced by the movement of the piston. This stroke fills the cylinder with a mixture of fuel and air at very nearly the pressure of the atmosphere. On the return stroke of the piston, all the openings leading from the cylinder are closed and the mixture is compressed. As the piston nears the end of this second stroke, which is known as the **compression stroke,** the igniter, or device, by means of which the charge is fired, is operated in time to produce full ignition of the mixture at the end of the stroke. The pressure rises to three or four times that due to compression, and drives the piston forwards on its next outward stroke, which is known as the **expansion,** or **power, stroke.** Just before, or as this stroke is completed, the exhaust valve is opened, permitting the burned gas and uncombined air to escape to the atmosphere, and during the following inward stroke practically all of this waste material is expelled. This last stroke is known as the **exhaust stroke.**

31. Graphic Representation of Four-Stroke Cycle. The four strokes of the engine cycle are shown in Figs. 8, 9, 10, and 11; above each figure is given an indicator diagram in which the line produced during the stroke shown in the figure is a full line, while the remainder of the diagram is shown in dotted lines. In all the figures, p denotes the piston; c, the cylinder; e, the exhaust valve; s, the inlet valve; i, the igniter,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s
p
c
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FIG. 8

r, the connecting-rod; *k*, the crankpin; *q*, the crank-shaft; and *a*, the crank. In the indicator diagram, the ordinates or vertical distances represent pressures, and the abscissas or horizontal distances denote the distance the piston has proceeded on its stroke. The pressures are measured from the dotted line *O V*, which represents the pressure of the atmosphere. The line *u* is the vacuum line, the full line *O v V* is the suction line, and the line *V f* is the compression line. At *f*, the charge is ignited, and *f g* denotes compression and explosion combined; *g h*, the vertical explosion line; *h j*, the expansion line; *j V*, combined expansion and exhaust; and *V w O* is the exhaust line. The pressures represented by the two lines *v* and *w* are slightly exaggerated, in order that the lines may be distinguished from the atmospheric line *o V*, which they follow very closely.

32. In Fig. 8 is illustrated the *suction stroke*, the crank-shaft turning in the direction of the arrow, and the piston having moved from the dotted line *n* to the position shown. The space between the end of the cylinder, when at the line *n*, and the cylinder head is called the **clearance space** or the **combustion chamber.** It should be noted that the inlet valve *s* is open and the mixed air and gas is being drawn into the cylinder, as shown by the arrows. The pressure within the cylinder drops slightly below the atmosphere, as shown by the line *v*. The valve *s* remains open until the piston gets to the right-hand end of its stroke. The numbers at the left of the diagram represent the pressures, and those at the bottom the volumes, corresponding to the cross-lines opposite which they are written.

33. When the piston starts on its return stroke, Fig. 9, the valve *s* is closed and the mixture is trapped within the cylinder and compressed. The rise of pressure during compression is shown in the indicator diagram by the line *V f*. When the compression has proceeded to *f*, a spark is produced by the igniter *i* and combustion begins. The rise of pressure from *f* to *g* is therefore due both to the compression and to the combustion of the gas. The flame spreads

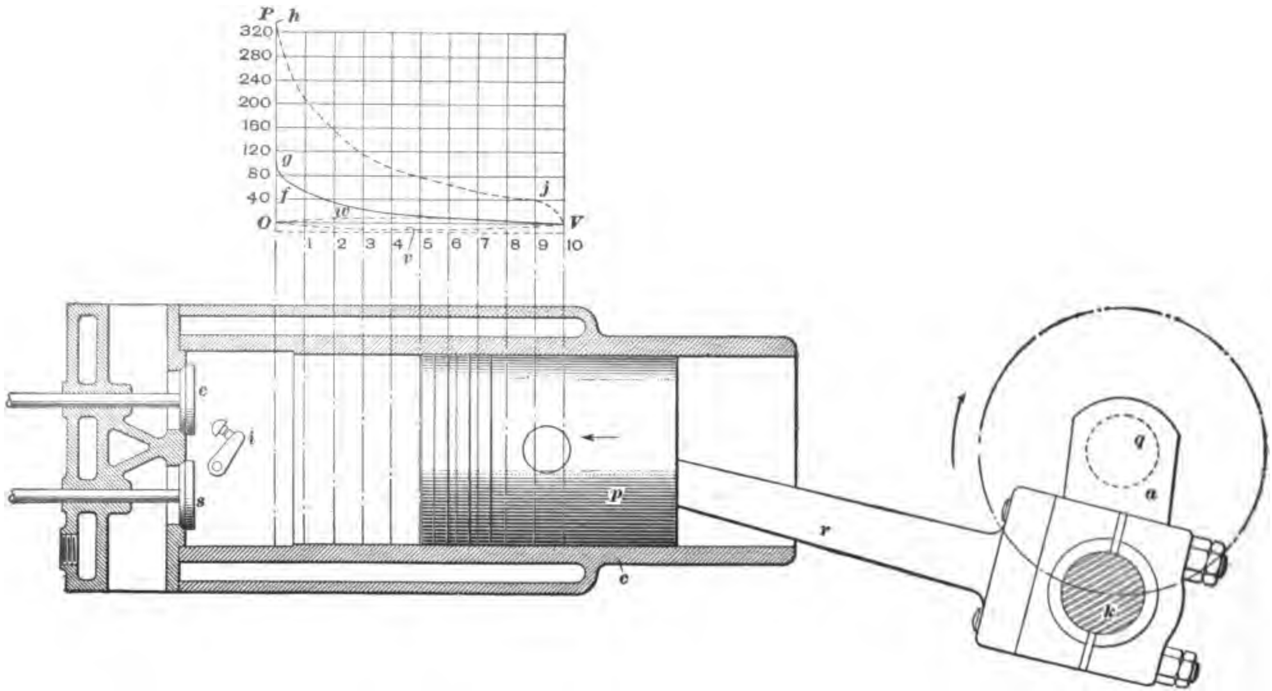
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FIG. 9

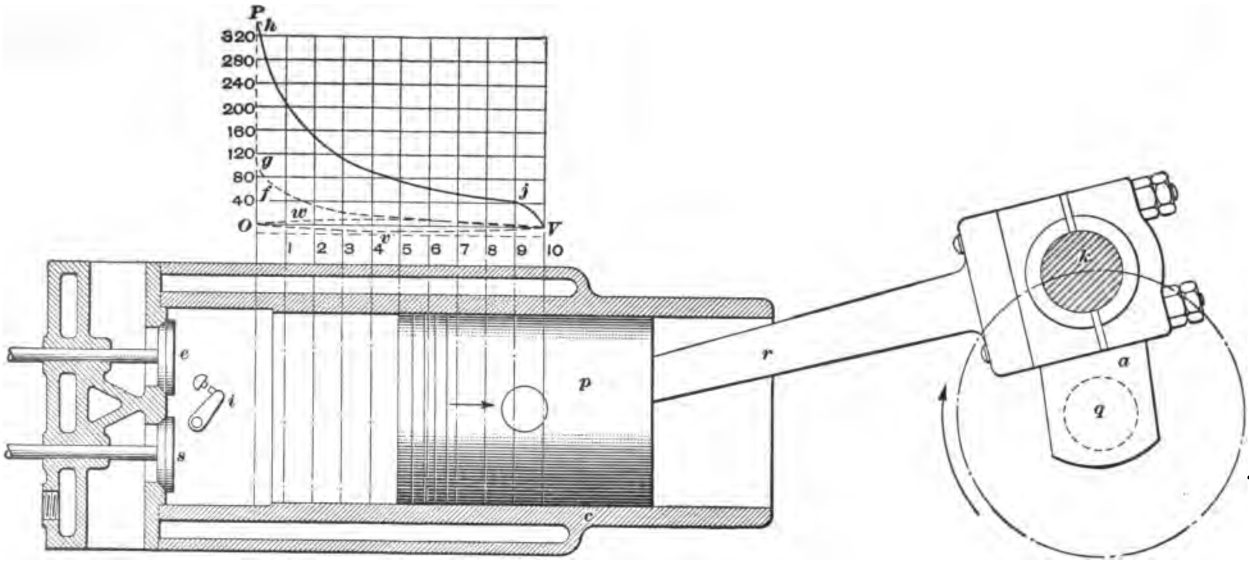
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FIG. 10

rapidly, and during the short time at the end of the stroke when the piston is practically at rest the pressure rises from g to h. This stroke is called the *compression stroke.*

34. In Fig. 10 is shown the *expansion stroke*, during which the pressure of the heated gases drives the piston toward the right, the pressure falling as the piston moves forwards, as shown by the drop of the line $h\,j$. When the expansion stroke has been nearly completed, the exhaust valve e is opened, and from j to V the drop of pressure is due both to expansion and to the escape of the gas through the exhaust valve. By the time the end of the stroke is reached, the pressure has fallen very nearly to that of the atmosphere, and the expanding gas has done its work.

35. In Fig. 11, the piston is returning, the exhaust valve e being open, and the gases are driven from the cylinder to prepare it for the reception of a new charge. There is a small rise of pressure during this stroke, due to the driving of the gas from the cylinder, and this is indicated by the line w. At the end of the exhaust stroke, the exhaust valve closes, and the succeeding outward stroke begins a new cycle with the suction of a fresh charge of gas and air.

36. The series of operations that take place during the four-stroke cycle are as follows:

FOUR-STROKE CYCLE

First Revolution

First Stroke.—Outwards; suction; inlet valve open; pressure falls below atmosphere.

Second Stroke.—Inwards; compression; both valves closed; pressure rises; ignition before end of stroke, followed by explosion and rapid rise of pressure.

Second Revolution

Third Stroke.—Outwards; expansion; both valves closed; pressure falls; exhaust valve opens near end of stroke.

Fourth Stroke.—Inwards; exhaust; exhaust valve open; pressure rises very little above that of the atmosphere.

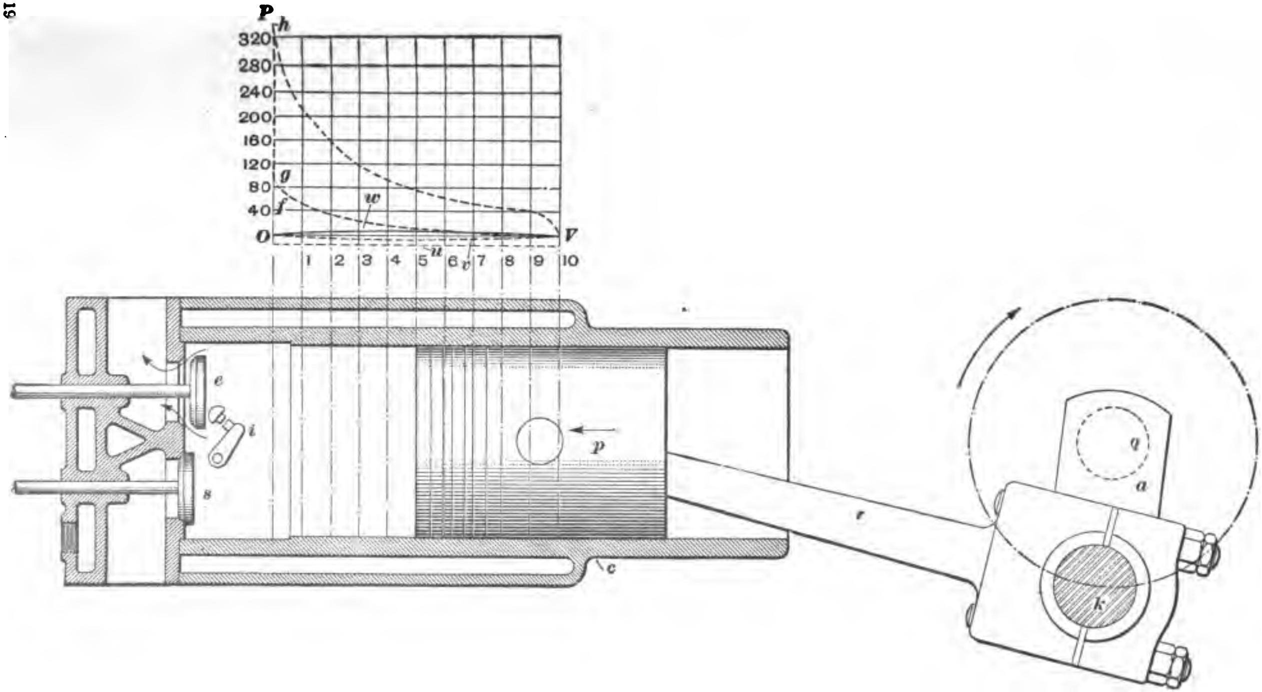
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FIG. 11

37. In the accompanying diagram, Fig. 12, the four strokes needed to complete the Otto cycle of operations are indicated by the spiral around the crank-shaft. The points of valve opening and closing, ignition, etc. are indicated on the spiral by letters, and similar letters with the subscript 1 show the corresponding positions of the piston. The indicator diagram above the cylinder shows the pressure in the cylinder for each position of the piston, and the reference letters with the subscript 2 on the diagram correspond to those on the spiral.

Starting with the piston at a_1 and the crank at a, the suction stroke continues until the crank reaches b and the piston b_1, at which point the inlet valve closes. The suction created by the rapid movement of the piston produces a slight vacuum in the cylinder, which is shown, exaggerated for clearness, by the drop in the dotted curve, from a_2 to b_2, below the line OV, which represents atmospheric pressure. With the inlet valve closed, the piston starts back, compressing the mixture to the pressures corresponding to points along the line b_2c_2. With the crank at c, and the piston at c_1, the charge is fired. An abrupt rise in pressure follows, shown from c_2 to d_2, most of the charge burning during the momentary dwell of the piston near the dead center, or end of the stroke. Combustion being complete and the piston moving out, the pressure begins to fall at d_2, the crank being at d. When the crank reaches e and the piston e_1, the exhaust valve is opened, and the gases escape during what remains of the expansion stroke from e_1 to f_1. The pressure having fallen at f_2 to that of the atmosphere, the piston drives out the remaining gases during its travel from f_1 to g_1, except that retained in the clearance space, and at g_1 the inlet valve opens and the cycle is repeated. The exact timing of the valves and the ignition will depend on the engine speed and other conditions and may vary considerably.

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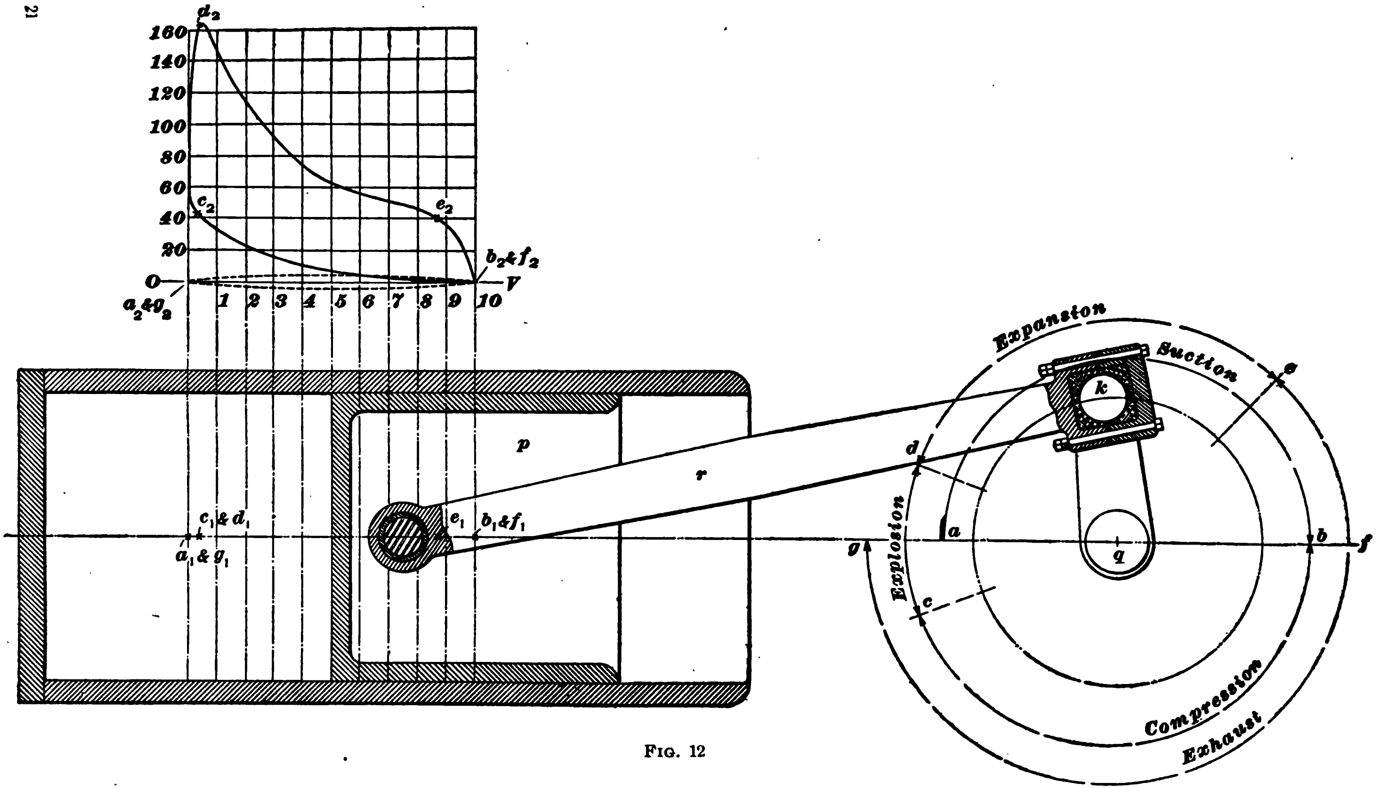

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c_1 & d_1
a_1 & g_1
e_1
b_1 & f_1
p
r
k
q
a
b
c
d
e
f
g
Expansion
Suction
Explosion
Compression
Exhaust

FIG. 12

THE DIESEL CYCLE

38. A modern form of the four-stroke cycle particularly adapted to oil engines is known as the **Diesel cycle,** having been named after its inventor. It differs from the ordinary four-stroke cycle in that *pure air only* is drawn in during the suction stroke and that the compression is continued until the pressure reaches between 450 and 550 pounds. The compression heats the air to about 800° F., and any fuel forced into the cylinder at this point will take fire and burn as it enters, in the same manner as gas burns while issuing from a burner. The fuel is burned until it is cut off or until there is no longer sufficient air to support combustion. In the Diesel cycle, oil is forced into the cylinder, with air, at a pressure of from 20 to 50 pounds above the pressure in the cylinder, and just as the compression stroke is completed. After the piston has proceeded a short distance on its expansion stroke, the fuel valve is closed and the expansion takes place as in the ordinary four-stroke cycle gas engine.

39. The operation of this engine is illustrated in Figs. 13 and 14. The various parts of the engine are lettered as in Figs. 8 to 11, except that there is no igniter. There is a small oil-fuel valve shown at *o*. Air only enters through the inlet valve *s* during the suction stroke, while the fuel is forced in, under pressure, through the valve *o* at the end of the compression stroke, which is the position shown in Fig. 13. The small space between the piston and the cylinder head is the clearance space; by comparing this with the larger clearance space of the ordinary four-cycle engine, as shown in Figs. 8 to 11, it will be seen that the compression in this engine is carried to a much higher pressure than in the ordinary four-cycle engine. This is also shown by comparing the point *h* of the diagram of this engine with that of the diagrams in Figs. 8 to 11. In Fig. 13, the suction pressure in the cylinder is represented by the line *v* of the diagram and the exhaust pressure by the line *w*, the suction stroke and the exhaust stroke being practically identical with that of the ordinary four-cycle engine.

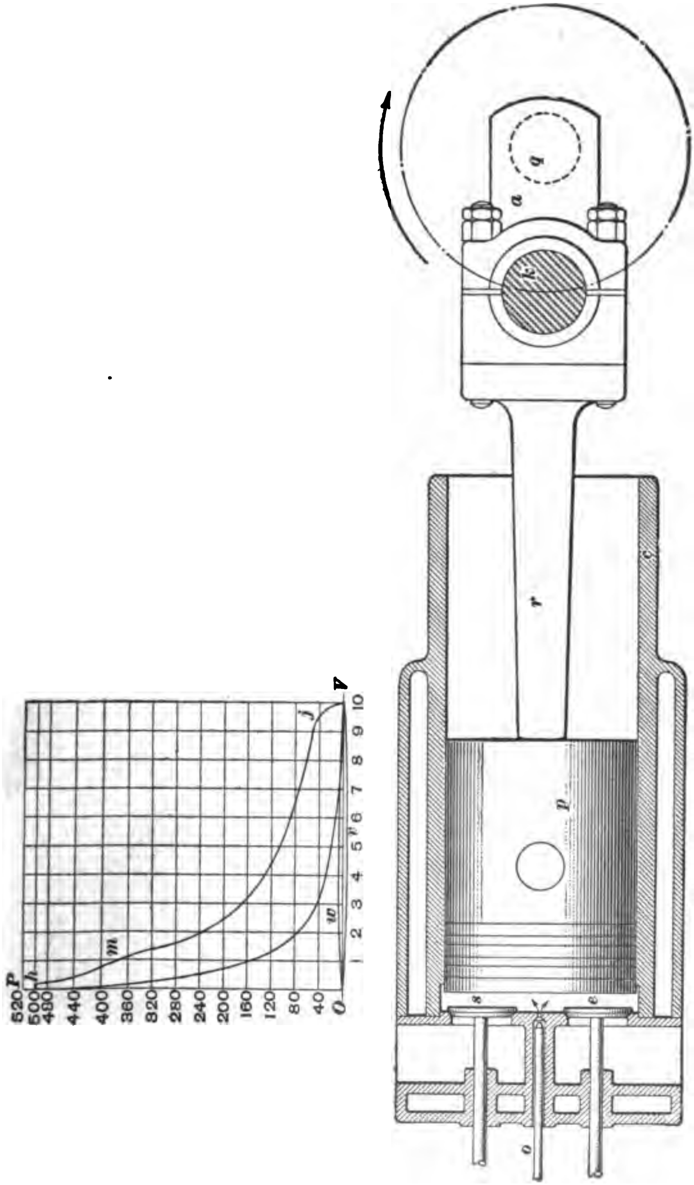
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FIG. 13

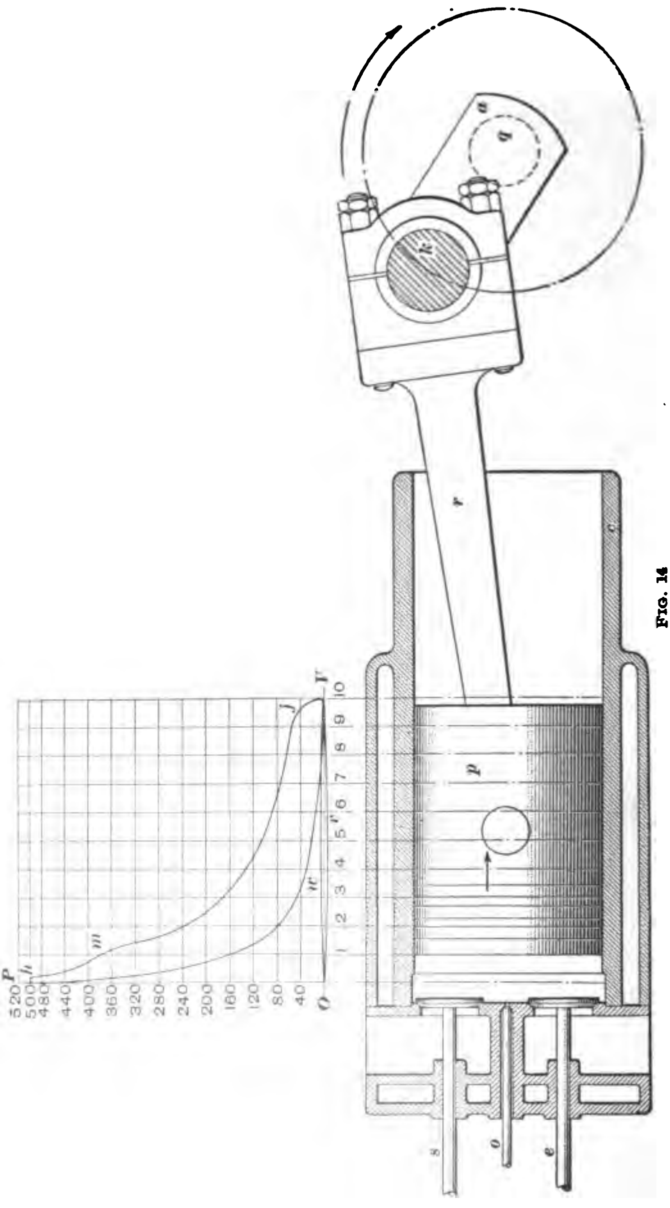
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FIG. 14

40. In Fig. 14, the piston is shown started on the expansion stroke, during the first portion of which combustion is taking place while the fuel is entering through the valve *o* In the figure, the valve *o* has just closed, combustion has about ceased, and expansion is beginning. The pressure drops slightly, while the fuel is still burning, as shown in the diagram from *h* to *m*; but the pressure is kept above the compression line by the heat of combustion. When the piston reaches the point having the pressure marked *m* in the diagram, the valve *o* is closed and combustion ceases, but the contents of the cylinder continues to expand until the exhaust valve opens at the pressure shown in the diagram at *j*.

41. The following tabulation of the Diesel cycle should be carefully compared with that of the ordinary four-stroke cycle:

DIESEL CYCLE

FIRST REVOLUTION

First Stroke.—Outwards; suction of air only; inlet valve open; pressure falls below atmosphere.

Second Stroke.—Inwards; all valves closed; compression; no combustion.

SECOND REVOLUTION

Third Stroke.—Outwards; oil valve open for early part of stroke; combustion during admission of fuel; expansion; pressure falls slowly during combustion and rapidly during expansion; exhaust valve opens near end of stroke; beyond this point the pressure rapidly falls to that of the atmosphere at the end of the stroke.

Fourth Stroke.—Inwards; exhaust; exhaust valve open; pressure rises slightly above that of atmosphere.

VARIATIONS OF FOUR-STROKE CYCLE

42. Careful observation of the diagram in Fig. 8 will show that there is considerable pressure, as shown at *j*, remaining in the cylinder at the time the exhaust valve opens. If by some means the stroke of the piston could be

made longer for the expansion stroke than for the suction and compression strokes, this pressure could be made available and considerably more work could be obtained from the gas. The diagram would be extended as shown by the dotted lines in Fig. 15, the scale of this diagram being the

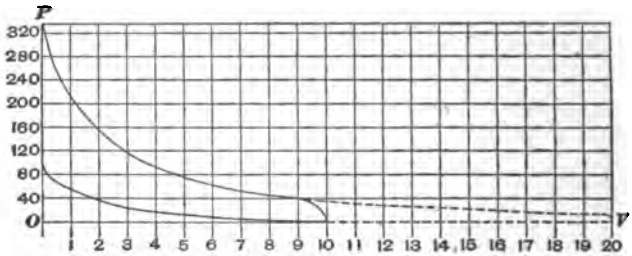
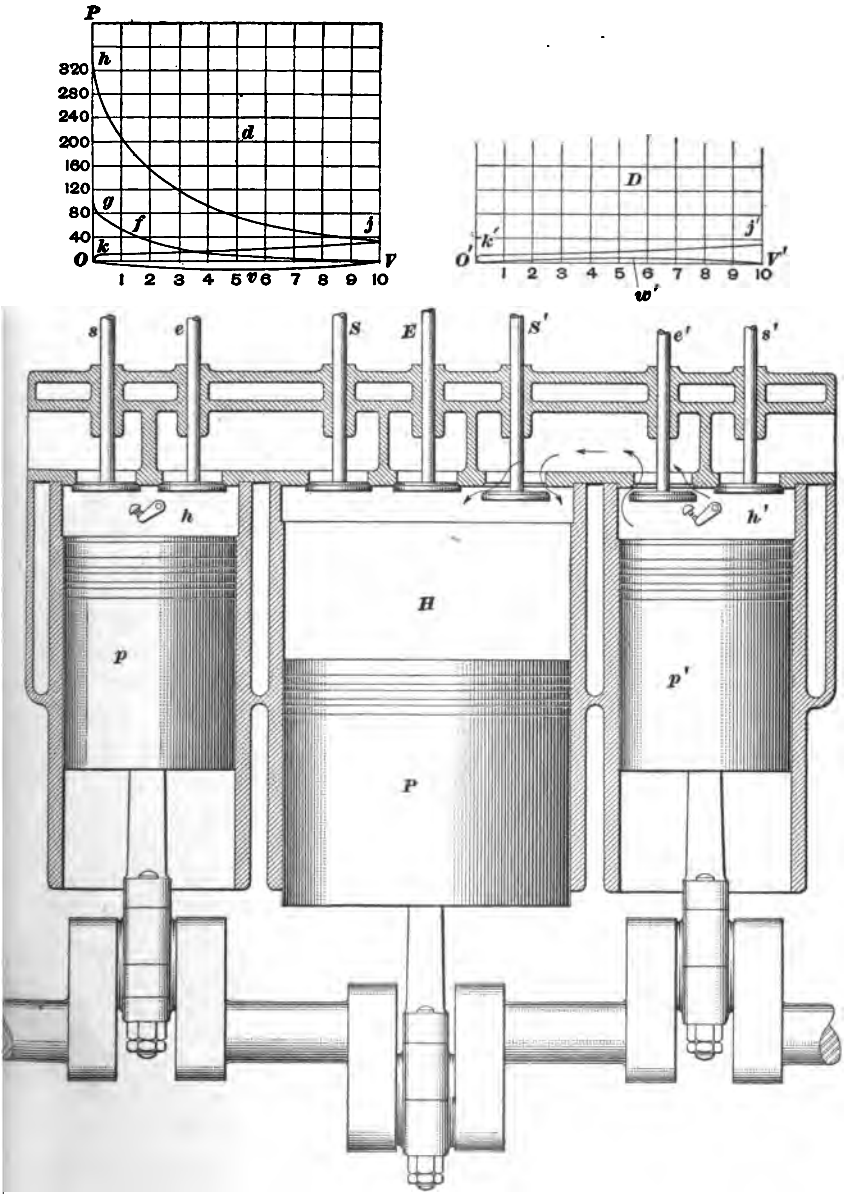


FIG. 15

same as in the diagram of Fig. 8; the theoretical gain is between 25 and 30 per cent. This may be accomplished in several ways. The earliest attempt was made by means of the **Atkinson variable-stroke engine**, a very complicated piece of mechanism and now no longer in use. Another method is known as **compounding**; in this, the exhaust gases pass into another cylinder of larger diameter and the expansion is continued nearly to the pressure of the atmosphere. Still another method is to close the inlet valve before the suction stroke is completed, allowing the piston to produce a partial vacuum in the cylinder, the pressure being restored on the return of the piston, and the compression above the atmosphere beginning when the piston has reached approximately a point in the suction stroke where the inlet valve was closed. This is known as the **variable cut-off engine.**

43. Compound Engines.—The compound engine is usually made with three cylinders, a high-pressure cylinder being located at each side of the low-pressure cylinder, as shown in Fig. 16. The engine illustrated is of the vertical type, with a low-pressure cylinder H and high-pressure cylinders h and h'. The cranks are 180° apart, so that the high-pressure pistons are together at the top of their stroke while


P
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160
120
80
40
O
h
g
f
k
d
j
V
1 2 3 4 5 v 6 7 8 9 10
D
k'
j'
O'
V'
1 2 3 4 5 6 7 8 9 10
w'
s
e
S
E
S'
e'
s'
h
h'
H
p
P
p'

FIG. 16

the low-pressure piston is at the bottom of its stroke. When the low-pressure piston moves up, the two high-pressure pistons move down, reaching the bottom of their stroke as the low-pressure reaches the top. The inlet valves of the high-pressure cylinders are at *s* and *s'*, *e* and *e'* being the exhaust valves. The low-pressure cylinder has two inlet valves *S* and *S'* and an exhaust valve *E*. The only difference between the cycles of the high-pressure cylinders and that of the ordinary four-stroke cycle is that the exhaust valve opens at the end of the stroke, but not before. The cycles in the two high-pressure cylinders alternate, that is, while expansion takes place in one, the other is taking in a new charge, and while compression takes place in one, the other is exhausting.

In the figure, cylinder *h* is compressing, with both valves closed; while cylinder *h'* is exhausting into the low-pressure cylinder, valve *e'* and valve *S'* being open and the piston *p'* moving upwards while the piston *P* is moving downwards. When the piston *P* has made about eleven-twelfths of its stroke, the exhaust valve *E* begins to open, and by the time the pistons reach the ends of their strokes the pressure within *h'* and *H* is down nearly to that of the atmosphere. By the time the end of the stroke is reached, the valves *e'* and *S'* have closed. The piston *p'* then starts on its suction stroke, while *H* is exhausting through the valve *E*.

44. The indicator diagrams obtained from this engine are shown at the top of the figure, the high-pressure diagram at *d* and the low-pressure diagram at *D*. The only difference between the diagram *d* and that shown in Fig. 8 is in the exhaust line. In Fig. 8, the exhaust begins before the piston reaches the end of the expansion stroke, where the pressure drops nearly to the pressure of the atmosphere and rises slightly again during the exhaust stroke. In Fig. 16, diagram *d*, the exhaust begins at the very end of the stroke and the pressure falls gradually to nearly atmospheric pressure during the exhaust stroke and drops to that of the atmosphere at the end. The suction, compression, and expansion lines are practically the same in both figures.

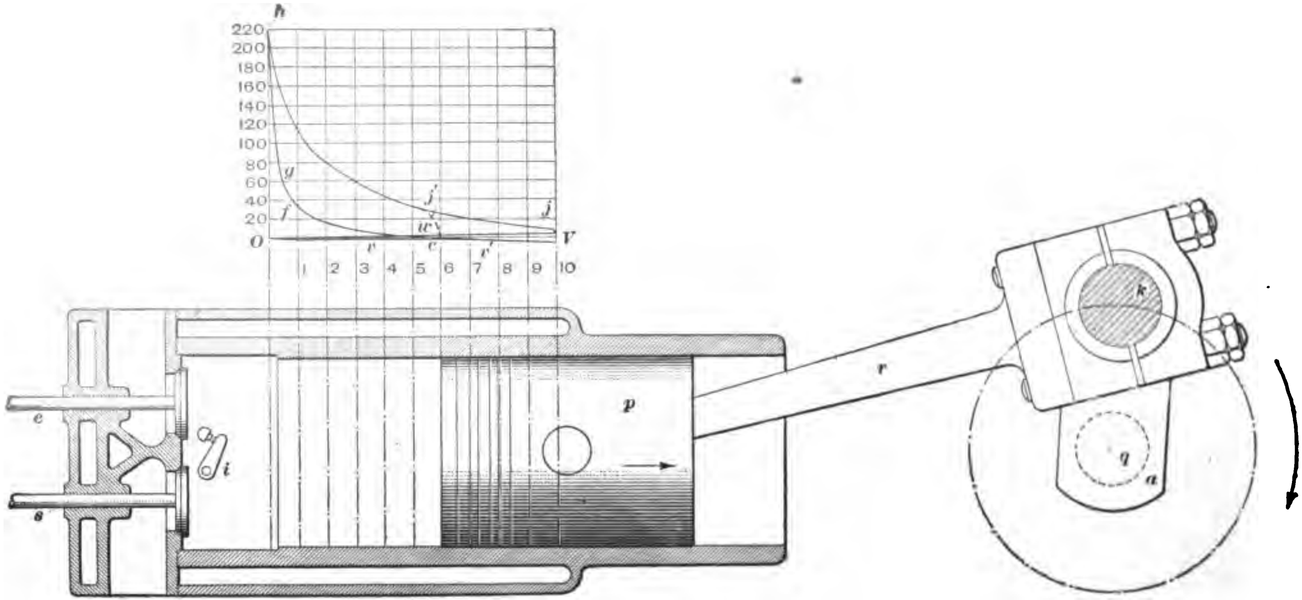
The line $j' k'$ of the indicator diagram D is identical on the down stroke with the exhaust line $j k$ of diagram d, and on the up stroke there is an almost imperceptible rise of the low-pressure exhaust line w', exaggerated in the figure, above the atmospheric line $O' V'$, due to the resistance of the exhaust passages.

45. The series of operations of the complete cycle in three-cylinder compound engines are as follows:

COMPOUND-ENGINE CYCLE

Cylinder h	Cylinder H	Cylinder h'
	First Revolution	
	First Stroke	
Downwards; suction; inlet valve open.	Upwards; exhaust; exhaust valve open.	Downwards; expansion; both valves closed.
	Second Stroke	
Upwards; compression; ignition; combustion; both valves closed.	Downwards; expansion; inlet valve open; exhaust gas entering from h'.	Upwards; exhaust valve open; exhaust into H
	Second Revolution	
	Third Stroke	
Downwards; expansion; both valves closed.	Upwards; exhaust; exhaust value open.	Downwards; suction; inlet valve open.
	Fourth Stroke	
Upwards; exhaust valve open; exhaust into H.	Downwards; expansion; inlet valve open; exhaust gas entering from h.	Upwards; compression; ignition; combustion; both valves closed.

46. Automatic Cut-Off Engine.—The principal difference between the cycle of the automatic cut-off engine and that of engines operated on the ordinary four-stroke cycle is that the fuel supply is cut off during the suction


h
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O
V
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9
10
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j'
j
w
c
v
v'
e
s
i
p
r
k
q
a

FIG. 17

stroke. In Fig. 17 is shown this type of engine, with the piston on the suction stroke just at the point where cut-off takes place. In this figure, the parts of the engine are lettered the same as in Figs. 8 to 11 and the indicator diagram is shown of the same length as in Fig. 8. It resembles the one in Fig. 15, except that it is shorter. This diagram is an exact copy of one taken during a test of an automatic cut-off engine, with the engine cutting off, that is, the inlet valve closing, at about six-tenths of the stroke. It should be noted that the suction line *v* drops slightly until cut-off takes place at *c*, and the continuation of this line in *v'* drops more rapidly toward the end of the stroke. This is caused by the movement of the piston beyond the point of cut-off, which produces a partial vacuum in the cylinder. On the return stroke of the piston, the compression line is practically identical with the line *v'* to the point *c*, crossing the atmospheric line *O V* near *c*, and then completing the compression, as in the ordinary four-stroke cycle, as if the stroke extended only from *c* to *O*. Ignition takes place at *f*, and the combustion line *f g h* is practically identical with the ordinary four-stroke cycle, except that, because this engine is usually made with a water-cooled piston, the compression may be carried much higher. The low pressure of the exhaust, as shown at *j*, is quite noticeable. The gain over the ordinary four-stroke cycle is shown in that portion of the card beyond the dotted curve *j'*. The exhaust line *w* is similar to that of the ordinary four-stroke cycle.

47. The series of operations in the automatic cut-off engine may be tabulated as follows:

AUTOMATIC CUT-OFF ENGINE

FIRST REVOLUTION

First Stroke.—Suction to cut-off; pressure falls slightly; inlet valve open until cut-off; expansion of mixture; pressure falls considerably.

Second Stroke.—Compression; ignition; combustion; pressure rises slowly to point of cut-off, then more rapidly to ignition; both valves closed.

SECOND REVOLUTION

Third Stroke.—Expansion nearly to atmospheric pressure; both valves closed; exhaust valve opens slightly before end of stroke.

Fourth Stroke.—Exhaust; exhaust valve open.

48. It should be noted that, in all the engines thus far described, the power impulse is received by the piston on one end only. This style of engine is known as a *single-acting engine*, no matter how many cylinders it may have. In the *double-acting engine*, the cylinder is closed at both ends and the power is transmitted through a piston rod and a crosshead. In the early days of gas-engine practice, it was thought impracticable to use a piston rod because the heat from the burning gas would cause the rod to cut and wear rapidly. It has been found, however, that this difficulty may be overcome by using a hollow rod and a hollow piston and passing water through them. At present, some of the larger high-powered engines are made double-acting, with valves at each end of the cylinder. In general construction, these engines are of the ordinary four-cycle automatic cut-off type, or are two-cycle engines with independent pumps, which will be described later.

TWO-CYCLE ENGINE

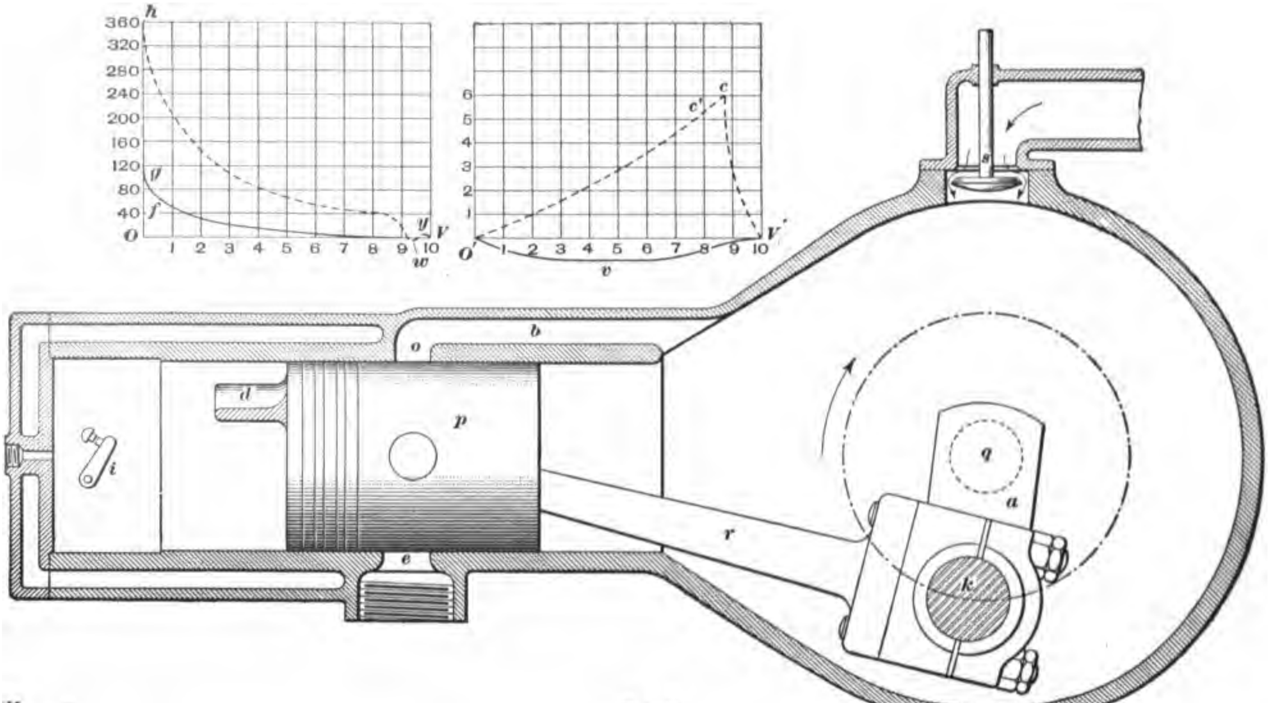
PRINCIPLES OF OPERATION

49. As explained in Art. **28**, two-stroke cycle, or, briefly, two-cycle engines are those which require two strokes of the piston, or one revolution of the crank-shaft, to complete the cycle. This is accomplished by eliminating the suction stroke and the exhaust stroke of the four-cycle type of engine. When the expansion stroke is nearly completed, the piston uncovers an opening in the cylinder wall, through which the exhaust gases readily escape, owing to their having a pressure of about 40 pounds above that of the atmosphere. By the time the piston has reached the end of the stroke, the pressure within the cylinder has fallen to that

of the atmosphere. The outgoing gas acquires such a velocity that its momentum causes the pressure within the cylinder to fall slightly below that of the atmosphere before the port is completely uncovered by the piston. After the pressure in the cylinder has fallen to about that of the atmosphere, communication is opened to a reservoir containing a mixture of gas and air under pressure. This compressed mixture rushes in and fills the cylinder and by the time the exhaust opening is closed by the returning piston, the cylinder is charged. It will be seen that, for such a series of operations, it is necessary to provide some method of pumping the mixture into the cylinder.

50. In the simplest form of two-cycle engine, the cranks, the connecting-rod, and the end of the cylinder nearest the crank-shaft are enclosed in a case, called the **crank-case.** While the piston is compressing the charge in the cylinder, a partial vacuum is formed in the crank-case, into which a charge of gas and air is drawn. While the piston is making its expansion stroke, the mixture in the crank-case is compressed to a few pounds pressure above that of the atmosphere, usually from 4 to 6 pounds. When the expansion stroke has been nearly completed, the exhaust port is uncovered by the piston, and when the exhaust port is uncovered sufficiently for the pressure in the cylinder to fall to about atmospheric pressure, the piston uncovers another port, called the **inlet,** or **transfer, port,** opposite the exhaust port and communicating with a passage, sometimes called the **transfer passage,** to the crank-case. This allows the mixture, already compressed in the crank-case, to rush through the inlet port and fill the cylinder with a fresh charge. This charging process, commencing before the exhaust has entirely escaped from the cylinder, assists in forcing out the exhaust gases.

51. Figs. 18, 19, and 20 are a series of illustrations showing the operation of a typical two-cycle engine, in which *p* is the piston; *q*, the crank-shaft; *a*, the crank; *k* the crankpin; *r*, the connecting-rod; *e*, the exhaust port;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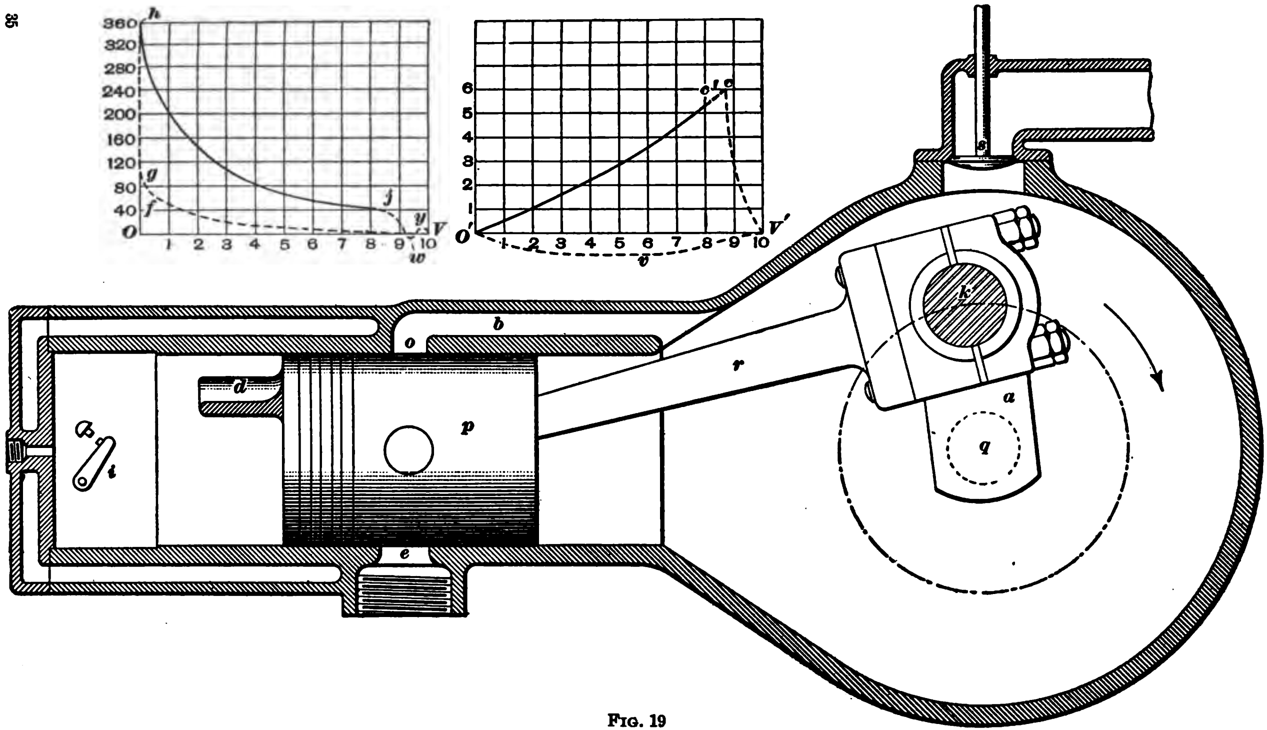
k

FIG. 18



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q
s

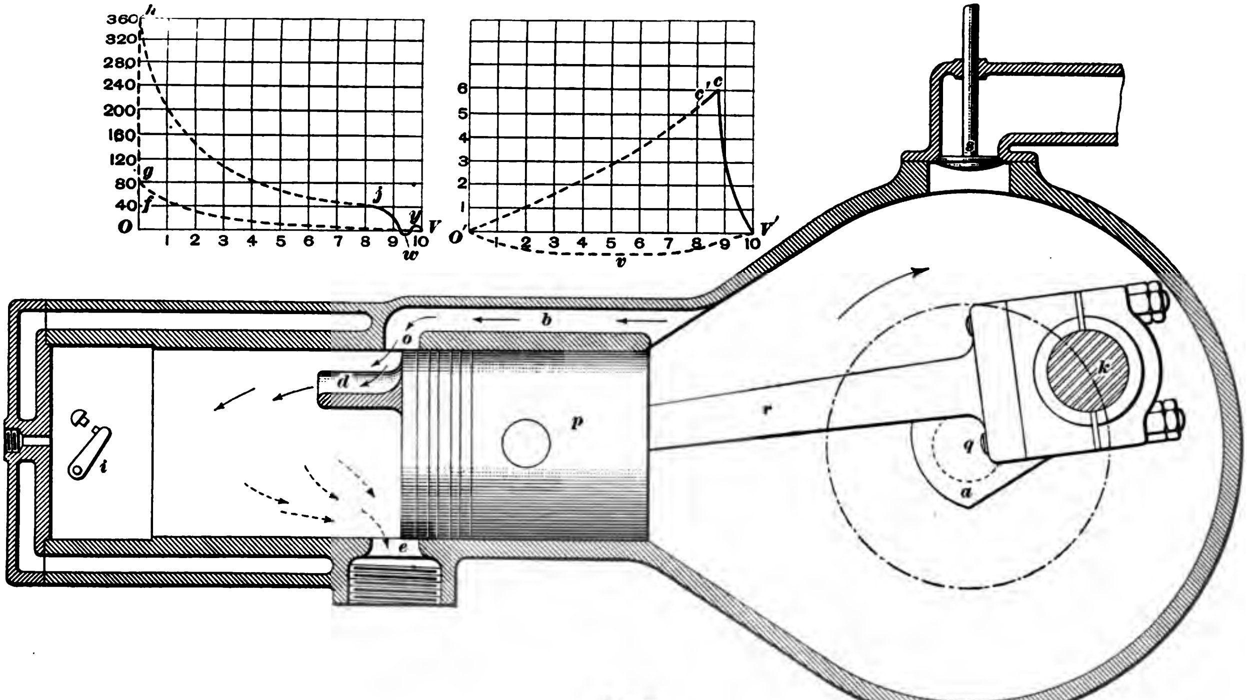
FIG. 19

o, the inlet, or transfer, port; *b*, the passage leading from the crank-chamber to the cylinder; *s*, the inlet valve; *d*, a deflector on the end of the piston; and *i*, the part of the igniting device at which the spark is produced. The diagram of pressures in the cylinder are shown above the engine and to the left, while the diagram for the pressures in the crank-case are shown to the right.

The difference between the diagram of this engine and that of the four-cycle engine should be carefully noted. In Fig. 18, the piston is moving toward the cylinder head, compressing the mixture of gas and air, while at the same time it is drawing a new charge into the crank-case through the valve *s*. That portion of the diagrams given during this stroke is shown by full lines. In reality, the first part of the cycle must always be the suction into the crank-case before any mixture is taken into the cylinder. The line *V f g h* is identical with the compression and explosion line of the four-stroke cycle, as shown in Fig. 9, and covers the same series of operations; namely, compression to *f*, where ignition takes place, increase of the rate at which the pressure rises from *f* to *g*, and the vertical explosion line *g h*. While the piston is compressing the charge in the cylinder, the crank-case is drawing more fuel through the valve *s*, the pressure in the crank-case falling below the atmosphere, as shown by the line *v* below $O' V'$. It should be noted that the diagrams for the pressures in the crank-case have a different scale of pressures from the scale of the diagrams for the pressures in the cylinder.

52. The next stroke of the piston is shown in Figs. 19 and 20. In Fig. 19, the piston is moving away from the head end, making the expansion stroke for the cylinder and the compression stroke for the crank-case, the inlet valve *s* being closed. This figure represents that portion of the stroke before the exhaust port *e* is uncovered, giving the portion of the indicator diagram from *h* to *j* for the cylinder and from O' to c' for the crank-case.

53. In Fig. 20, the piston is very near the end of its stroke, both the inlet and the exhaust ports *o* and *e* are open,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4
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1
O′
c′
c
V′
v
b
o
d
e
p
r
k
q
a
i
s

Fig. 20

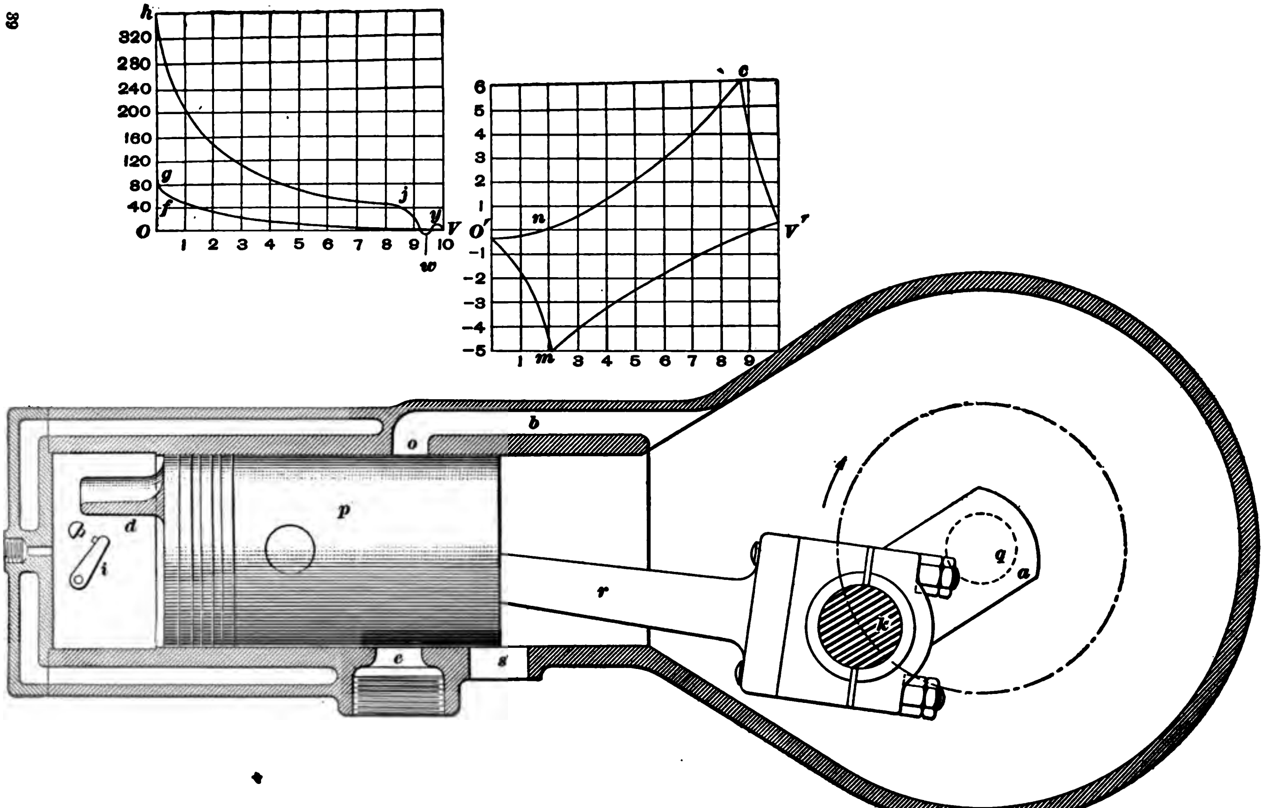
and the exhaust gases are escaping from the exhaust port *e*, as shown by the dotted arrows, while the fresh charge is entering through the by-pass *b* and port *o*, and is thrown by means of the deflecting plate *d* toward the cylinder head, as shown by the full arrows. The momentum of the column of exhaust gas as it leaves the cylinder is so great that, unless there is considerable resistance in the exhaust passage, the pressure falls below that of the atmosphere, as shown by the small loop *w*, and is raised slightly, as shown by the loop *y*, when the fresh charge enters from the crank-case. If the engine is properly proportioned, none of the new mixture will escape at the exhaust port *e*, as it will be closed before the fresh charge has reached it. During this part of the stroke, the pressure in the crank-case rises from c' to c and then drops to V', when the transfer port is opened. The following inward stroke compresses the new mixture in the cylinder and draws a new charge into the crank-case, as illustrated in Fig. 18, thus beginning a new cycle.

54. The series of operations taking place during the two-stroke cycle are as follows:

TWO-STROKE CYCLE

CYLINDER	CRANK-CASE
FIRST STROKE, INWARD	
Compression; pressure rises; ignition near end of stroke, followed by explosion and rapid rise of pressure.	*Suction;* inlet valve open; pressure falls below atmosphere.
SECOND STROKE, OUTWARD	
Expansion; pressure falls; exhaust followed by entrance of fresh mixture from crank-case.	*Compression;* pressure rises to from 4 to 8 pounds; charging cylinder; pressure falls to atmospheric pressure.

55. Three-Port Two-Cycle Engine.—In some forms of two-cycle engines, especially those designed for high speeds, a piston-opened port is used instead of the inlet-valve *s* shown in Figs. 18, 19, and 20. This port is so located that it is opened by the crank-case end of the piston as the


h
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V
w
1 2 3 4 5 6 7 8 9 10
6
5
4
3
2
1
-1
-2
-3
-4
-5
O'
n
m
c
V'
1 3 4 5 6 7 8 9
b
o
d
i
p
r
e
s
k
q
a

FIG. 21

piston approaches the inner end of the stroke. During that portion of the inward stroke before this port is uncovered, the piston produces a partial vacuum in the crank-case, which is filled during the short interval in the two strokes that the port is uncovered.

This type of two-cycle engine is illustrated in Fig. 21, in which *s* indicates the third port, while the remainder of the engine is practically the same as in the engine already shown and the parts are lettered the same. In the three-port type of engine, the indicator card for the crank-case is of slightly different form. During the inward stroke, the pressure within the crank-case falls until the point *m* is reached. When the piston passes the outer edge of the port *s*, the mixture rushes in, causing the pressure to rise to that of the atmosphere at the point *n*, just about the time the outer edge of the port *s* is covered on the outward stroke of the piston. The pressures in the crank-case that are below atmospheric pressure are shown below $O' V'$, and the number of pounds below the pressure of the atmosphere are marked with the minus sign, as -1, -2, etc., at the left of the crank-case diagram. The diagram within the cylinder is the same as with the check-valve type shown in Figs. 18, 19, and 20.

56. Variations of the Two-Stroke Cycle.—The enclosed crank-case in the types of two-cycle engine described is nothing more nor less than an air pump. The variations of this form of engine are principally in the air pump and the connections of the air pump to the cylinder. In some forms of the enclosed crank-case type, the mixture from the case is carried through a long by-pass to the top of the cylinder and admitted through a valve located in the top of the cylinder head. This valve is held against its seat with a light spring, the pressure of which is overcome by the pressure in the crank-case, and the deflecting plate is omitted. Still another variation is made by enclosing the front end of the cylinder, using a piston rod and cross-head and guides, and admitting the mixture either through a piston-opened port or through a slide valve.

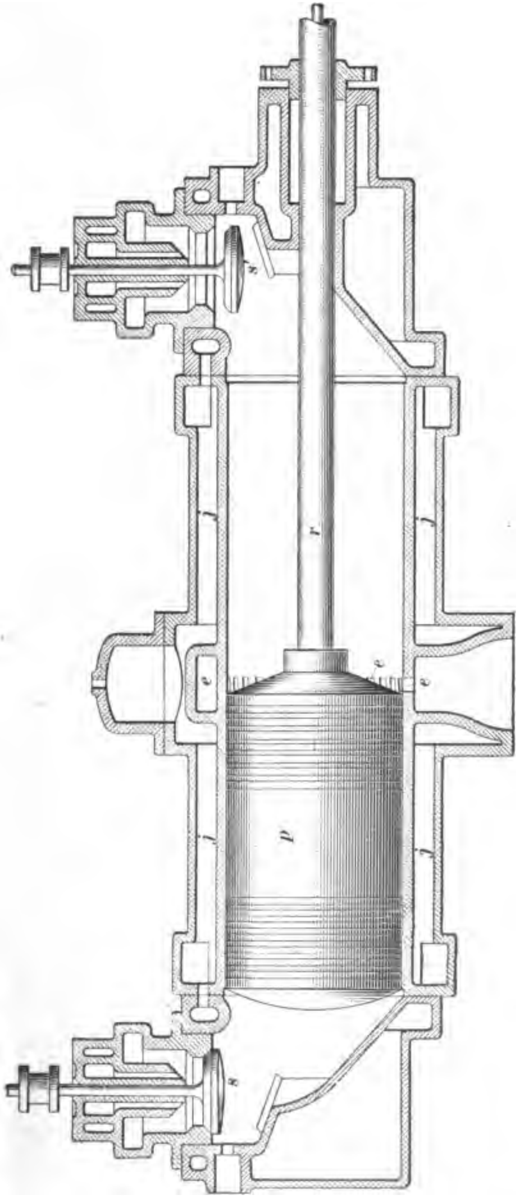


FIG. 22

57. In all types of two-cycle engines thus far described, it should be noted that the work of the expanding gas is done on one side of the piston only, the other side being used for the air pump. The disadvantage of this method is that the parts required for the air pump must be strong enough to resist the pressure of the explosion, as the same parts are used for the working end of the piston. The engine may, however, be made double-acting, but it is then necessary to provide a separate air pump. But the work to be done by the pump is comparatively light, and the total weight of the double-acting engine, together with the air pump, is therefore not nearly so great as that of two single-acting engines of the same bore and stroke.

58. Koerting Engine.—In Fig. 22 is shown the main cylinder of the **Koerting** two-cycle engine, which operates with an independent pump, or, in fact, two independent pumps. This type of engine is adapted for using blast-furnace gas, which is very weak in heating power, and hence a little more gas than air is required. Gas and air are supplied by two independent pumps, and are forced into the cylinder through valves s, s'; exhaust from either end of the cylinder takes place through the piston-opened port e. The piston p is made very long, being only a little shorter than the stroke of the engine, which is double-acting. Work is done on each end of the piston alternately; hence, there are two explosions to every revolution. As shown in the figure, the crank end of the cylinder is exhausting, the crank-pin being on the inner dead center. Valve s' is open and the fresh air is coming in, followed by a mixture of air and gas. The fresh air is allowed to enter first, in order to clear the cylinder of burned gas, a cleaning process known as **scavenging**. The valves s, s' are open during a small portion of the stroke only. The valves and the cylinder are entirely surrounded with a water-jacket j. The piston p is made hollow, and a stream of water is constantly driven through the hollow piston rod r and around the inner surface of the piston, returning through the piston rod by

means of a central tube. Gas engines of this type are made in single units as large as 2,000 horsepower.

59. The two-cycle type of engine is extremely simple, as it has few moving parts. On the other hand, some power is unavoidably wasted, because the exhaust valve or port must be opened earlier than is necessary in the four-cycle engine, owing to the extremely short time in which the exhaust gases must be discharged. Moreover, there is some unavoidable mixing of the fresh charge with the burned gases, since they cannot be sharply separated, and it is quite possible in many cases for a portion of the fresh charge to escape from the exhaust port unburned. If this sort of loss is to be avoided, the alternative is to restrict somewhat the quantity of fresh charge transferred to the cylinder, so that a smaller quantity of the fresh mixture enters the cylinder than would be used in the four-cycle engine, and the power is correspondingly smaller. The mean effective pressure of a four-cycle engine is seldom less than 65 pounds per square inch, using gasoline, and is nearly always above 50 pounds on full load. An average figure for the mean effective pressure of a two-cycle engine would be from 35 to 45 pounds. Another source of loss is the compression of the charge in the crank-case. The power used in doing this is not recovered, as is the power used in compressing the charge in the cylinder, for the reason that the gas is simply released by uncovering the transfer port and does no work on the piston. For these and other reasons a two-cycle engine is not often used in small sizes where economy of fuel consumption is important; but its small first cost makes it popular for launches and similar use, in which fuel economy is of less consequence than simplicity of operation.

AUTOMOBILE AND MARINE ENGINES

FOUR-CYCLE GASOLINE ENGINES

WATER-COOLED AUTOMOBILE ENGINES

CLASSIFICATION OF AUTOMOBILE ENGINES

1. The broad classification of gas engines into stationary, marine, and automobile engines stands for differences in design and construction. As the stationary engine is intended, first of all, to realize high fuel economy, and to last for many years with but a nominal amount of care bestowed on it, it is made slow running and substantial in all its parts. In small and medium sizes, it weighs anywhere from one to several hundred pounds per horsepower.

The marine engine occupies an intermediate position. If intended for use in a working boat, as for oyster dredging or the like, or for long cruises, it is heavily built and run at a comparatively low speed. If, on the other hand, it is intended for racing, or for light and high-speed boats, it is built as light as possible. In the modern high-speed *automobile boats*, as they are sometimes called, the weight of the engine is considerably more than that of the hull, and as much as 100 horsepower has been put into a boat not more than 40 feet long over all. Such marine engines are made to run as fast as possible, durability being a secondary consideration; nevertheless, the skill that has been brought to

bear on their design has made it possible to obtain a surprising degree of endurance from light and seemingly fragile constructions.

The same, with regard to lightness and endurance, may be said of automobile engines. Economy of weight is here of the first importance, as a heavy motor necessitates building the remainder of the vehicle accordingly. Complete automobiles are built to weigh much less per horsepower than even the lightest stationary engines, and engines of over 100 horsepower have been put in racing automobiles weighing not more than 2,204 pounds, which is the present limit of weight for racing machines.

In nearly all American automobile engines, gasoline is used. In Europe, several concerns have built successful kerosene engines for motor vehicles; and, in France and Germany, alcohol or a mixture of alcohol and benzine has been used experimentally with considerable success, although in France alcohol can hardly as yet be considered a serious commercial factor.

CHARACTERISTICS OF AUTOMOBILE ENGINES

2. Nearly all automobile engines are of the four-cycle type. Although a number of manufacturers have experimented with the two-cycle engine, only a few have turned out commercially successful engines of this type. Owing to the high compression, heavy flywheel, and considerable structural rigidity required by the Diesel kerosene-oil engine, it has been found altogether unsuited to automobile service.

The typical automobile engine has from one to four cylinders, is small and compact, and is of light weight and high speed. The maximum power of single-cylinder engines is about 10 horsepower, and four-cylinder engines are built as small as 10 or 12 horsepower. The compression is from medium to high, and some sort of a float-feed carbureter is employed. The inlet valve is sometimes automatic, and sometimes mechanically operated; the latter type predominates. The engine is controlled almost exclusively by

throttling the ingoing charge, although a few years ago the French engines were commonly governed by a mechanism that caused the inlet valve to remain closed when the speed of the engine rose above a given point. This is known as the *hit-or-miss system of governing.* Almost all the higher-powered engines have centrifugal governors, in which the governing action depends on the centrifugal force of rotating weights and may be modified by the operator as desired, to increase or retard the speed of the engine. The charge is ignited by electric spark, and the cylinders may be vertical or horizontal. As a rule, the smaller, single-seat automobiles, known as *runabouts*, are equipped with single-cylinder horizontal engines, as these are the cheapest to build.

3. Sometimes there are two cylinders opposed horizontally about one crank-shaft, as shown in Fig. 1, in which *a*

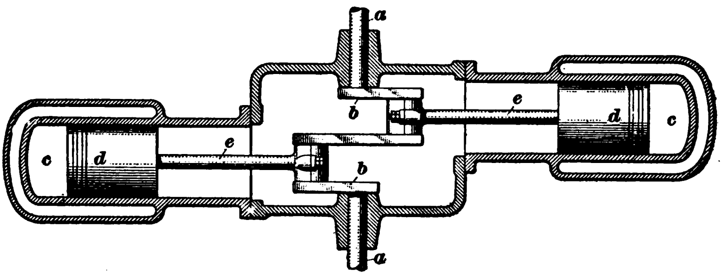


FIG. 1

is the crank-shaft. The cranks *b*, *b* are 180° apart, and the cylinders *c*, *c* are slightly offset to match the offset of the cranks. The pistons *d*, *d* and connecting-rods *e*, *e* move at all times in opposite directions at equal speeds, and the effects of their inertias are therefore opposite and equal. If it were possible to build the cylinders exactly in line, there would be no mechanical vibration at all, but owing to the offset there is a slight rocking effect, which, however, is practically negligible. The only objection to these engines is that they are rather long.

4. In two-cylinder engines of this type, it will be observed that the pistons are making out or in strokes at the same

time; that is, while one piston is passing through its power stroke, the other is making its suction stroke. As the suction and power strokes are separated by the compression and exhaust strokes, it follows that the impulses with this type of engine will occur at equal intervals, alternately from one and then the other cylinder. This would not be the case, however, with the cylinders placed side by side, or in twin-cylinder engines, as in Fig. 2, and with the cranks opposite each other, that is, 180° apart. In this case, two

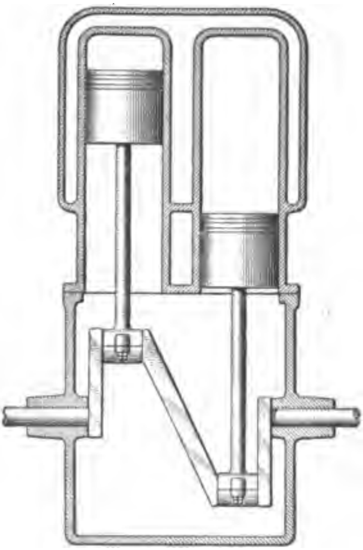


FIG. 2

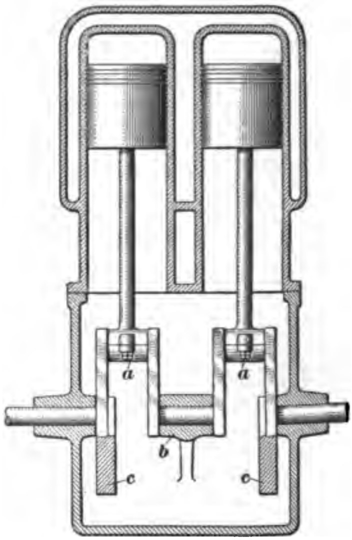


FIG. 3

power impulses would occur on successive strokes, and for the remaining two strokes there would be no impulse. As this would result in a jerky running of the engine, the arrangement shown is not a popular one, although the mechanical or piston vibration would not be excessively great. It is more common in twin-cylinder engines to work the two pistons on crankpins *a*, *a* whose axes are in line with each other, as in Fig. 3, or, if the motor is small, to make the two crankpins in one and dispense with the center bearing *b*. The cranks are balanced by the

weights *c*, *c*. It is impossible with this construction to balance the pistons properly, since, if the counterweights on the cranks were made heavy enough to balance the pistons completely at the ends of the stroke, there would be at the middle of the stroke an unbalanced lateral effort resulting from the centrifugal force of the counterweight, which would introduce crosswise shaking. On account of the unavoidable vibration, this type of engine is disappearing.

5. Automobile engines are also built with three vertical cylinders, as shown in Fig. 4. This form is, however, used

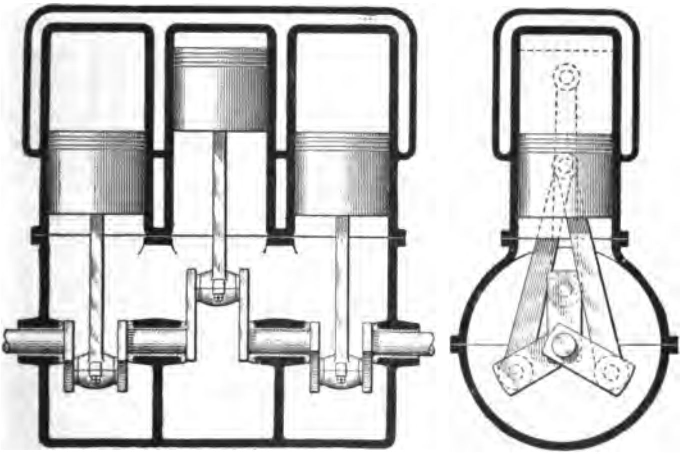


FIG. 4

more frequently in marine and stationary service. It can be shown mathematically that in this type of engine the sum of all the upward forces due to inertia of the reciprocating parts is at all times equal to the sum of all of the downward forces, so that, if it were possible to bring all the cylinders into one common axis, there would be no vibration whatever from inertia. Since this is manifestly impossible, there remains a slewing vibration due to the offset of the pistons. The cranks in this engine are spaced 120° apart around the crankshaft. As a complete cycle requires two revolutions, and there are three cylinders delivering impulses in that period, it follows that there are three power impulses in

every four strokes, which makes a very smooth-running engine, and renders it unnecessary to put much weight into the flywheel.

Automobile engines of the two-cycle type are built with three vertically arranged cylinders and with cranks set 120° apart, delivering to the crank-shaft three power impulses per revolution, thus producing approximately the same turning effect as the four-cycle type of engine having six cylinders.

6. When it is desired to build the engine as light as possible, it is advantageous to have more than one cylinder

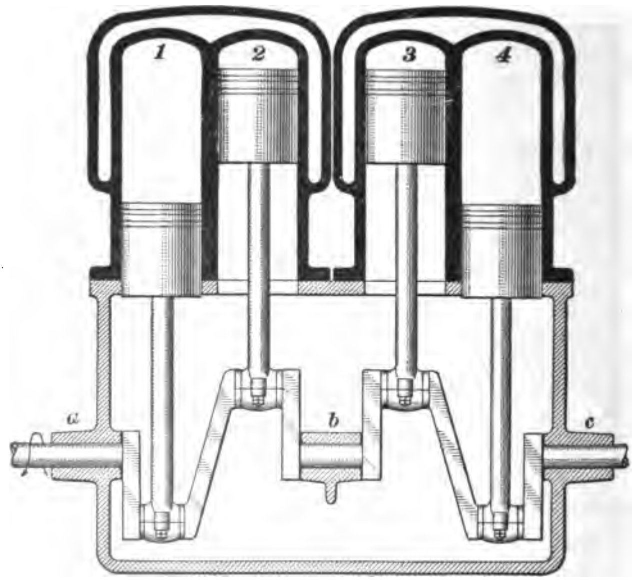


FIG. 5

—in fact, to have three or four—for the reason just pointed out, that the more cylinders there are, the lighter the fly-wheel can be. On the other hand, the more cylinders there are, the more it costs to construct the engine. It follows from this that the highest-grade automobile engines in all powers above 10 or 12 horsepower are built with four or more cylinders, and with these a machine is obtained that runs very smoothly.

7. When economy in first cost is not the main consideration, the engine, if of more than 10 to 14 horsepower, generally has four cylinders, arranged as shown in Fig. 5. The cranks are arranged in pairs, as shown, the one pair being set at 180° to the other pair. This gives an almost perfect mechanical balance, and as there is one power stroke for every stroke of the engine a very smooth-running engine is the result. Automobile engines are almost always vertical, and located under a **bonnet**, or **hood**, in front of the dashboard, partly for the sake of convenience in arrangement, and partly also because a vertical engine is less subject to fouling through an excess of oil working up from the crank-case into the combustion chamber. In some instances, the crank-shafts have only three bearings, shown at *a*, *b*, and *c*, Fig. 5, while in others there is a bearing between every pair of cylinders, making five bearings in all. Sometimes, also, the cylinders are cast in pairs, and sometimes independently, the latter arrangement commonly being used with the five-bearing crank-shaft.

8. Some automobile engines are built with six and even eight cylinders. The reason for using six cylinders is that one power impulse is begun before the preceding one is completed, so that there is always a turning effort. This makes it possible to run the engine very slowly indeed without stopping. Eight-cylinder engines have been used mostly in racing cars, the cylinders being air-cooled, this method of cooling being adopted because it is somewhat more convenient to air-cool a large number of small cylinders than a few large ones.

Owing to the fact that it is easy to direct an abundant stream of air on the cylinders of an automobile engine, air cooling for engines of small and medium size is quite popular. As the subject of air cooling requires separate consideration, attention will first be given to water-cooled motors in the several arrangements just mentioned.

SINGLE-CYLINDER ENGINES

9. An example of the single-cylinder horizontal type of engine is shown in Fig. 6. The crank-case *a* encloses the end of the cylinder *b*, and is provided with a cover *c*, which is made removable for the purpose of inspecting the interior or for pouring in oil. The crank *d* carries the counterweight *e* to balance the crank and connecting-rod *f*. The piston *g* is made very long, and has three rings held by pins to prevent them from turning. The piston is ribbed internally to give strength and yet make it as light as possible. The inlet and exhaust valves are mechanically operated; only one of them, *h*, is shown. It is taken out for replacement or grinding by unscrewing the plug *i*. The valves *h* are opened by means of the two-to-one pinion and gear *j* and *k* and cams *l*, the motion being transmitted to the valves through push rods *m*. The rods are guided at both ends in bearings, and are offset, as shown, for the purpose of bringing the rods *m* in line with the valves. The end of *m* on which the cam acts carries a small case-hardened steel roller; *n* is the water-jacket, *o*, *o* are drainage cocks, and *o'* is a compression relief cock. The engine is suspended at the points *p*, *p*, from cross-members of the automobile frame.

10. In Figs. 7 and 8 is shown a type of small vertical single-cylinder engine in which the crank-case is enclosed and is large enough to contain the flywheels, which, although small in diameter, are quite heavy. The crankpin is made with a taper fit in the flywheels, which are thickened where the pin passes through, and the two halves of the crank-shaft are also made with taper fits in the flywheel hubs, and are further secured by keys. The flywheels are steel castings, and opposite the crankpins they have counterweights cast on them inside the rim. Engines of this sort are run at very high speeds; and in order to do this without undue mechanical vibration, the piston and connecting-rod are made as light as possible. The principal parts, in detail, are as follows: *a* is the crank-case, divided vertically and bolted

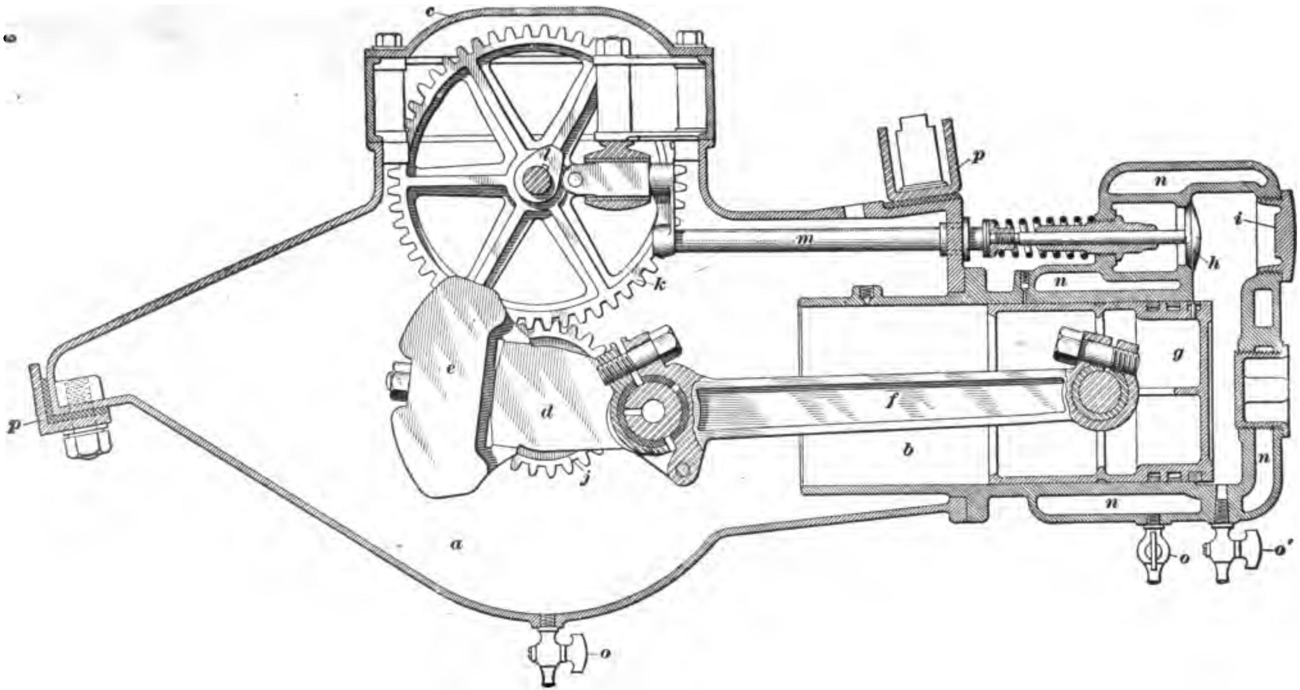


FIG. 6

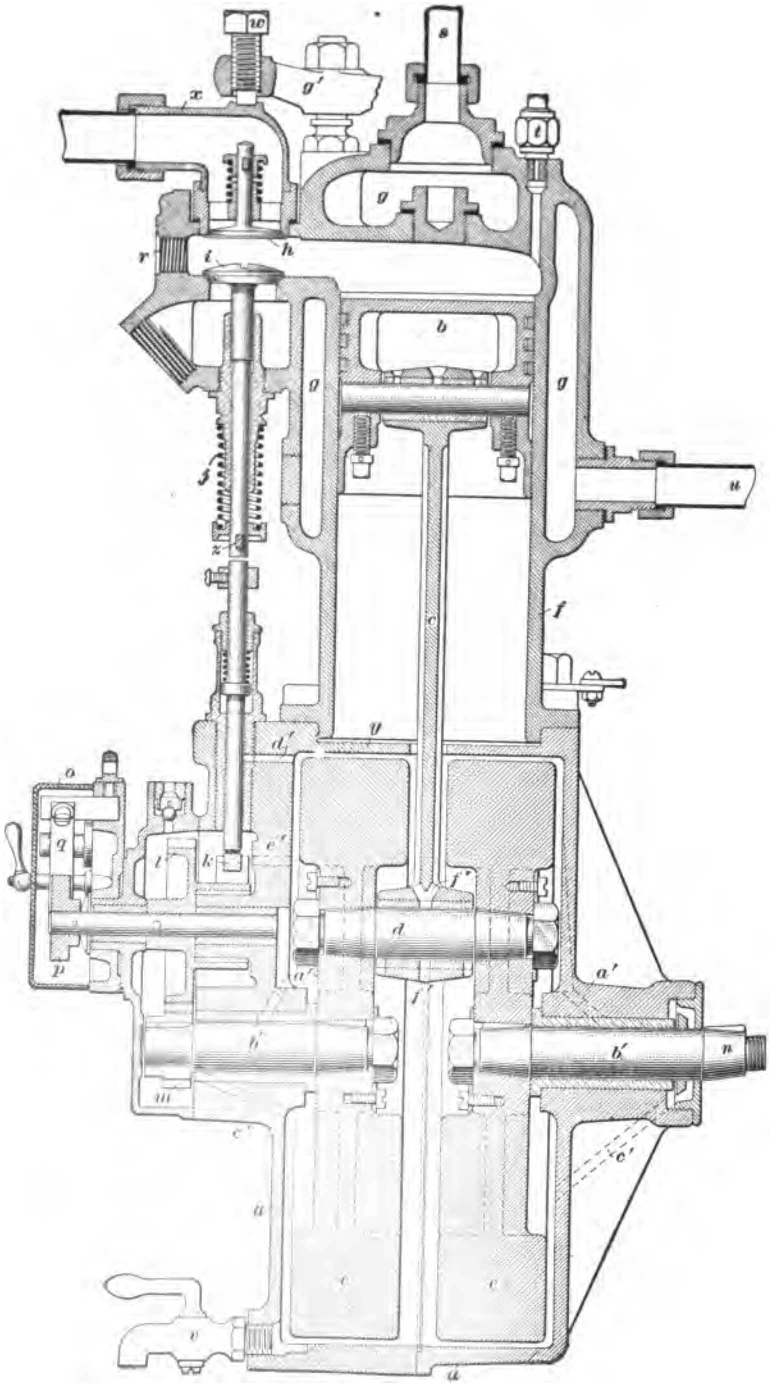


FIG. 7

together by through bolts; *b*, the piston; *c*, the connecting-rod; *d*, the crankpin; *e, e*, the flywheels; *f*, the cylinder; *g*, the water-jacket; *h*, the inlet valve; *i*, the exhaust valve; *j*, the exhaust-valve spring; *k*, the exhaust-valve cam; *l*, the two-to-one gear; *m*, the two-to-one pinion; *n*, the end of the crank-shaft, tapered to receive a driving pinion by which the power of the engine is transmitted; *o*, an aluminum cover enclosing the spark timer; *p*, a cam for timing the electric spark that causes the ignition, known as the *spark-timing cam; q*, the contact spring of the spark timer; *r*, a threaded hole into which the spark plug is screwed; *s*, the outlet for circulating water; *t*, a relief cock for use in starting; *u*; the jacket water intake; *v*, a drainage cock for emptying the crank-case of oil; *w*, a setscrew that holds down the elbow casting *x*; *y*, a baffle plate to prevent an excess of oil from being thrown from the flywheels into the cylinder; *z*, the exhaust-valve stem key.

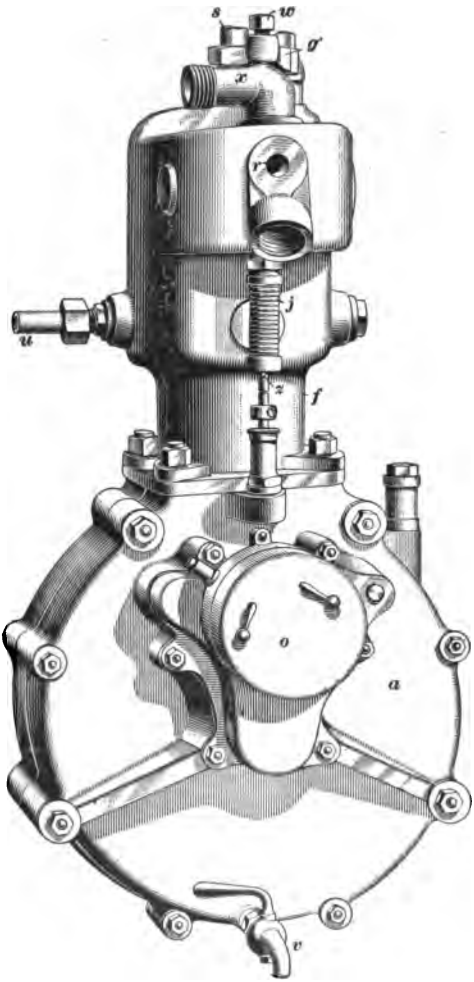


Fig. 8

The casting *x* holds down the inlet-valve cage against the force of the explosion, which tends to drive it out. By slackening the screw *w* and lifting off *x*, the inlet-valve cage, with the valve attached, can be lifted out for inspection or regrinding of the valve. As indicated, the operation of the inlet valve is automatic, being opened by suction and closed by the spring shown.

11. The parts of the engines shown in Figs. 6 and 7 are lubricated by what is known as the **splash system**, by which a quantity of oil is held in the lower portion of the crank-case, and the crank, as it rotates, throws the oil to the working surfaces. The oil for this purpose is pumped into the crank-case about once in 25 miles. As the fly-wheels extend to the bottom of the case, it is sometimes necessary, in order to prevent the oil from being thrown up into the cylinder in excessive quantities, to provide the baffle plate *y*, Fig. 7, which intercepts all the oil except that which goes up through the slot in which the connecting-rod works.

Part of the oil running down the upper half of the crank-case is caught by the oil holes a' shown in dotted lines, and conducted to the centers of the crank-shaft bearings b', b'. A part of this oil works inwards, and the portion that works out to the outer end of the bearings is thrown off by the two-to-one pinion *m* at one end, and by the centrifugal oil ring shown on the other end of the shaft, and is carried back to the crank-case by the return holes c', c', shown below the bearings in dotted lines. At the top of the crank-case a lateral oil hole d' leads to the push rod of the exhaust valve *i*, and a little lower down is another hole e' shown in dotted lines, which carries oil to the cam *k*. Oil reaches the crankpin through the oil holes f' in the large end of the connecting-rod, and a small amount of oil spray reaches the wristpin in the same way.

Access to the exhaust valve *i* is had by taking out the inlet valve and turning to one side the yoke g', in which the setscrew *w* is held. Then, by slightly compressing the

exhaust-valve spring, the key *z* may be slipped out, thus freeing the valve from its spring *j*.

In Fig. 8 is shown an outside view of the engine, the same reference letters being used to indicate the visible parts.

DOUBLE-CYLINDER ENGINES

12. Horizontal Types.—Horizontal engines having two opposed cylinders, of the type shown in Figs. 9 and 10, are constructed along the same general lines as the engine shown in Fig. 6. In some cases, one exhaust cam operates both exhaust valves, and one inlet cam operates both inlet valves; but, in the engine illustrated by Figs. 9 and 10,

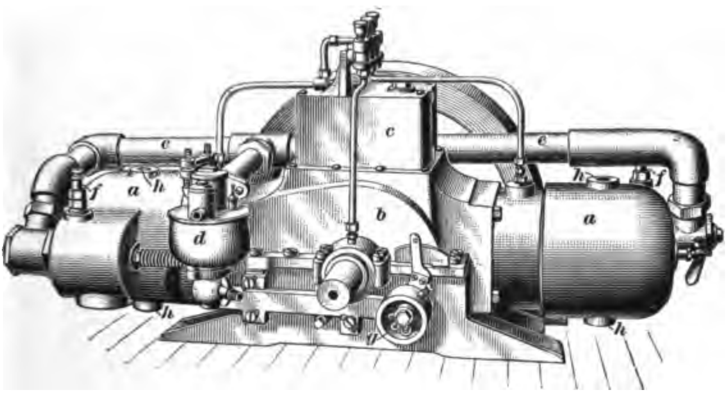


FIG. 9

the inlet valves are automatically operated. As the cylinders are necessarily offset in a horizontal plane, on account of the offset in the cranks, it is usually necessary to provide a corresponding offset in the valve push rods or their operating mechanism, or in the valve chambers themselves.

Referring to Fig. 9, the two cylinders *a*, *a* are bolted to a common crank-case *b*, on the cover of which is mounted a mechanical lubricator *c* for lubricating the pistons and bearings. Connection between the carbureter *d*, in which the fuel is vaporized, and the inlet-valve chambers of the two cylinders is made by the supply pipe *e*. The charge is

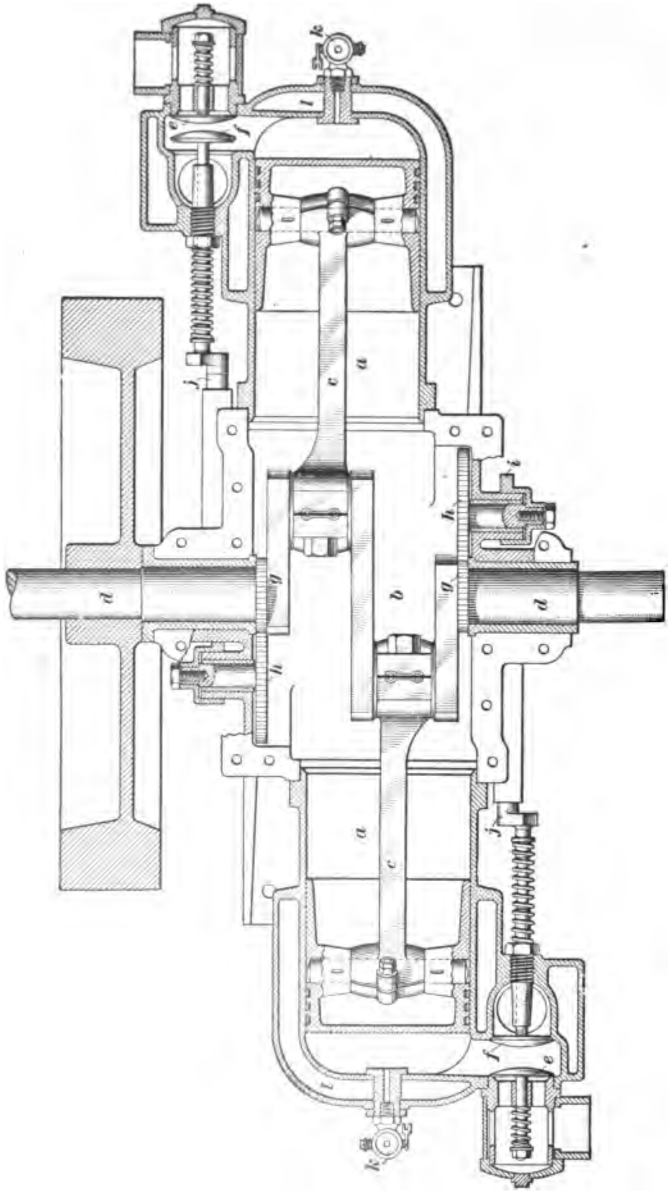


FIG. 10

gnited by the spark plugs *f*, *f*, the time of the spark being ontrolled by means of the timer *g*. The cooling-water conections to both cylinders are made at *h*, *h*.

Reference to the sectional view, Fig. 10, shows how the ylinders *a* are arranged with reference to each other and to he crank-case *b*, the offset in the cylinders necessitating an ffset in the connecting-rods *c*, which are attached to cranks 80° apart. By thus setting the cranks and arranging the ylinders in opposition, the crank-shaft *d* receives a power npulse at each revolution, with no gap or uneven interval 1 the time of the impulse. The explosive mixture enters he cylinders through automatic inlet valves *e*, the burned ases passing out through the exhaust valves *f* mechanically perated by means of the two-to-one gears *g* and *h*, the shaft n which the latter is mounted carrying the exhaust-valve am *i*, against which presses the roller of the exhaust-valve ush rod *j*. Compression relief cocks *k*, mounted in a bushng that passes through the cylinder water-jackets *l*, are proided for relieving the compression pressure in starting. The structural elements of this engine are similar to those f the engines previously described, and hence no extended iscussion of operation or construction is necessary.

13. Vertical Types.—With vertical engines having nore than one cylinder, it is customary to locate the inlet nd exhaust valves at one side of the cylinders, as shown in Figs. 11 and 12, which are respectively an end view and a ide view of a vertical double-cylinder engine. Both views re partly in section. The principal parts are as follows: , the crank-case, divided horizontally in the plane of the rank-shaft; *b*, the cylinder; *c*, the water-jacket; *d*, the piston; , the connecting-rod; *f* and *g*, two-to-one pinion and gear; , the inlet valve; *i*, the exhaust valve; *j*, the spark plug; , the cam-shaft; *l*, the centrifugal governor, which acts on he throttle lever *m* through the long lever *n*; *m* and *n*, the ever mechanism that controls the throttle valve; *o*, a centrifigal circulating pump, for circulating the water through the vater-jacket, driven by a pinion meshing with the two-to-one

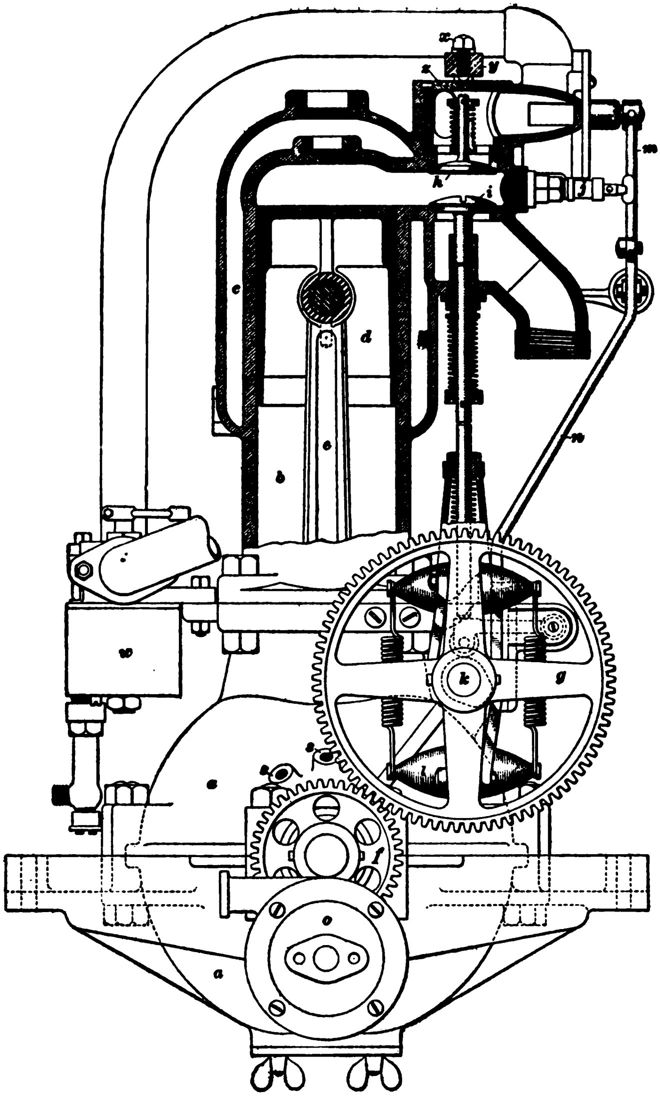


FIG. 11

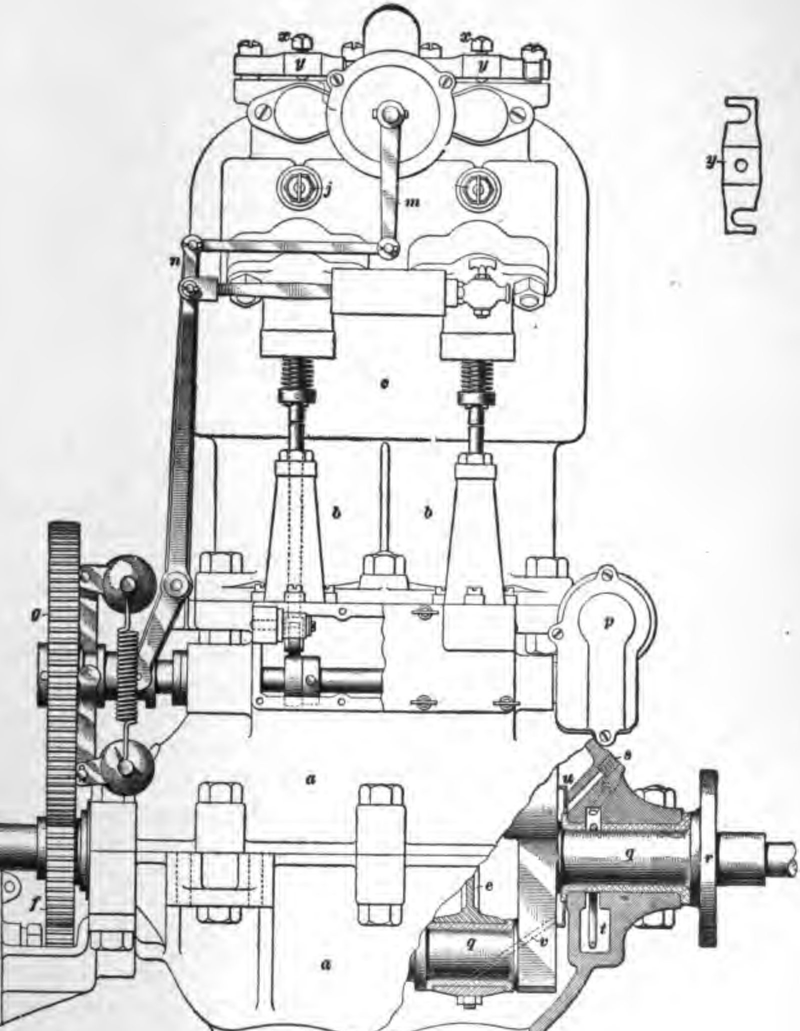


FIG. 12

pinion; *p*, the housing of a shaft lying transversely, driven by spiral gears at the same speed as the cam-shaft, and carrying at its other end (not seen) the spark timer; *q*, *q*, the crank-shaft and crankpin; *r*, the flange to which the flywheel is bolted; *s*, *s*, the oil-pipe connections for supplying oil to the cylinders and main bearings; *t*, the oil ring running on the crank-shaft and dipping into the oil well below, there being one of these rings at each main-shaft bearing; *u*, a ring that catches the oil fed by a mechanical oiler through the adjacent hole *s*, and leads it by the drilled hole *v* to the crankpin bearing.

The carbureter *w* takes air from a point near the cylinder, where it is warmed, and delivers it by the L-shaped mixing pipe shown, to a cast connection at the top of the cylinder through which it passes, going through the throttle valve and then to both of the inlet valves. The throttle valve is usually of the butterfly type, and is provided for the purpose of controlling the power developed by the engine by regulating the quantity of vapor that enters the cylinders. The inlet valves are taken out by slackening the setscrews *x* and giving a quarter-turn to the yokes *y* that hold the setscrews *x*. As shown in the detail sketch in the upper right-hand corner of Fig. 12, the ends of the yokes *y* are slotted in opposite directions to receive the studs that hold them, and a fraction of a turn releases them from the studs. Then the castings *z* can be lifted out, thus permitting the removal of the inlet valves and their cages, and of the exhaust valves after them.

MULTICYLINDER ENGINES

14. The cylinders *a* of the four-cylinder automobile engine shown in Figs. 13 to 17 are cast in pairs. Looking toward the flywheel end, the inlet- and exhaust-valve mechanism appears on the left-hand side of the engine, as indicated in Fig. 15. Of the accompanying illustrations, on all of which similar parts are indicated by similar reference letters, Fig. 13 is an end elevation of the engine looking toward the end opposite the flywheel. Fig. 14 is a longitudinal

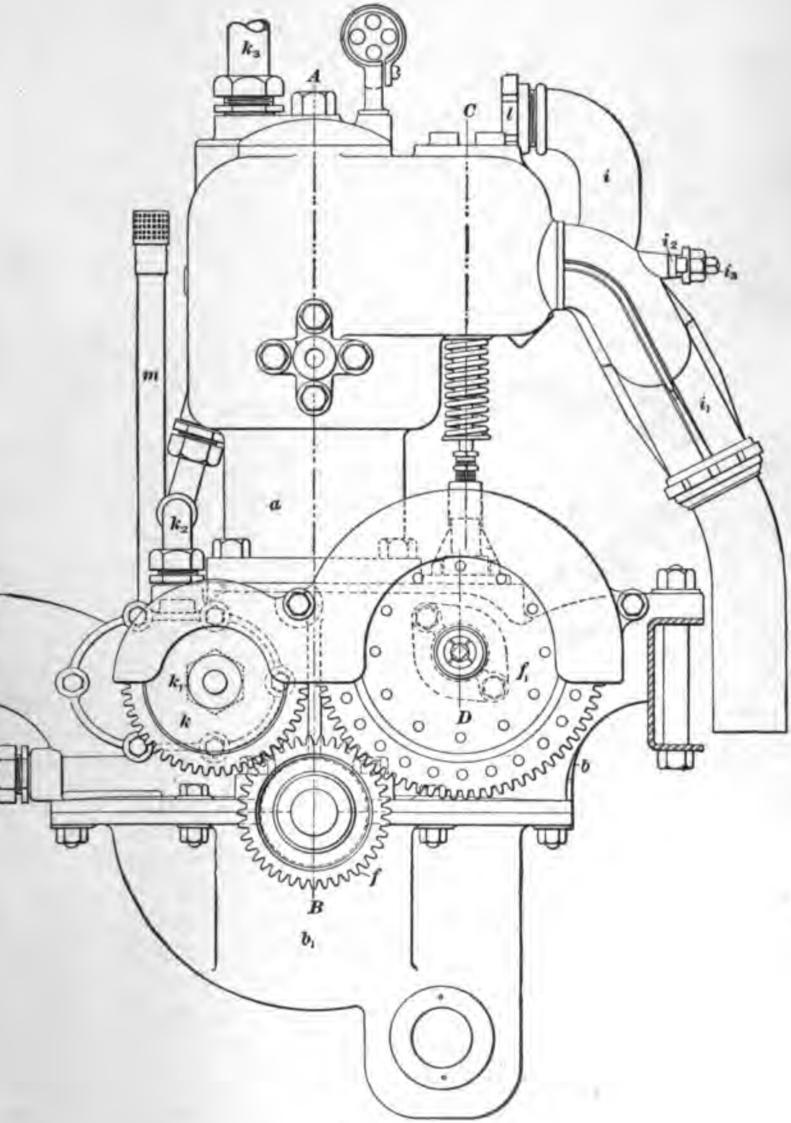
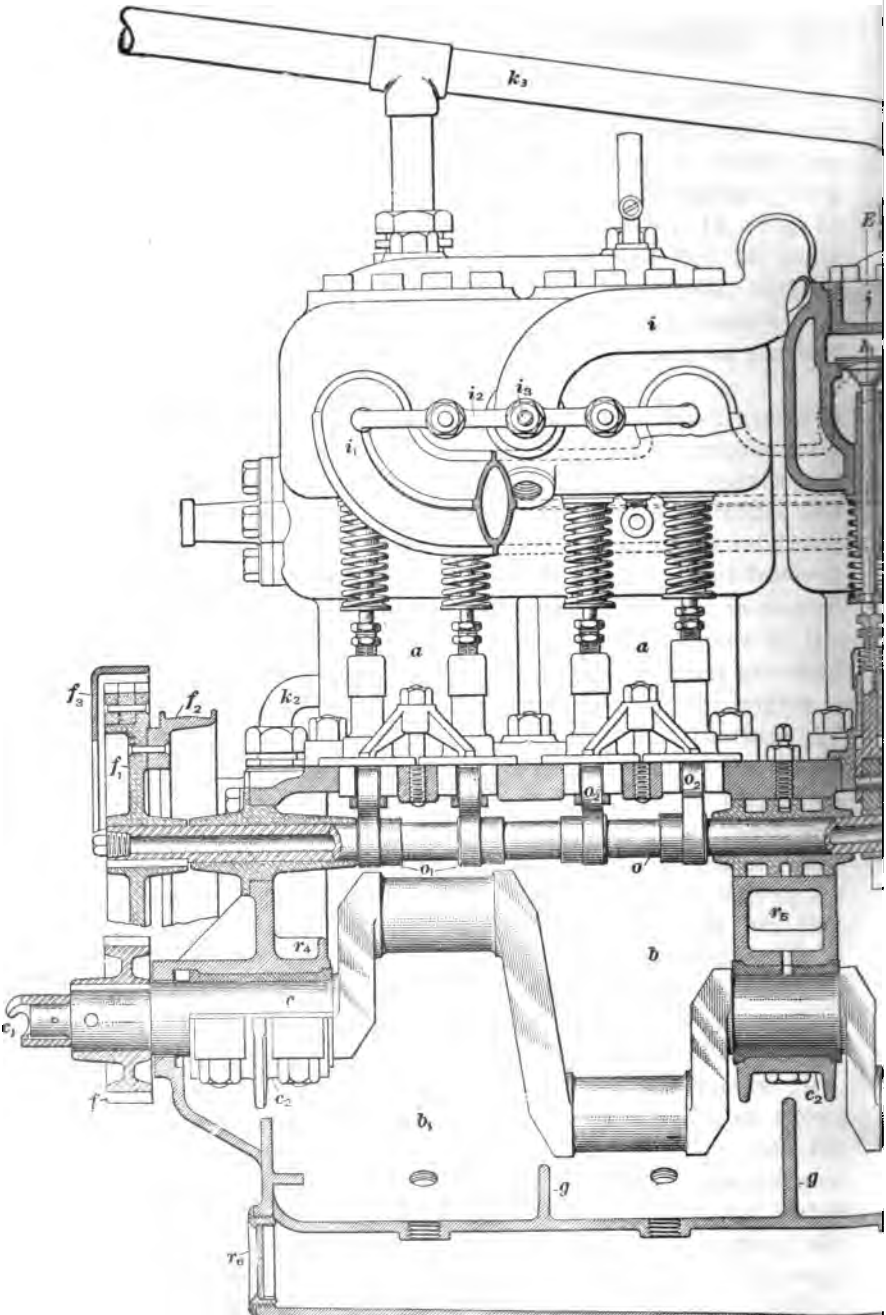


Fig. 13

elevation partly in section, the cylinder *a* at the extreme right, together with the crank-case *b*, b_1 and crank-shaft bearings, being shown in a section taken on the center line *A–B* of Fig. 13, and the valve-operating mechanism being shown in a section taken on the line *C–D* of Fig. 13. Fig. 15 is a sectional elevation along the line *E–F* of Fig. 14, while Fig. 16 is a plan view, shown partly in section, looking down on the top of the engine. Fig. 17 is a sectional elevation of the timer and force-feed oil pump taken on the line *G–H* of Fig. 14.

Both the inlet and exhaust valves, which have cast-iron heads screwed and riveted on steel stems, are mechanically operated from a single cam-shaft. The inlet valves are placed adjacent to each other in each pair of cylinders and communicate with a common inlet port. Letters of reference applying to the principal parts of the engine are as follows: *a*, *a*, *a*, *a*, the four cylinders, one of which is shown in section in Figs. 14 and 15; *b*, b_1, the top and bottom halves of the crank-case; *c*, the crank-shaft; c_1, Fig. 14, a ratchet provided to engage the hand crank, by means of which the engine is started; c_2, the bottom caps of the crank-shaft bearings, by which the shaft is supported from the top half of the crank-case, so that the lower half can be removed for inspection (shown in section in Fig. 14); *d*, the piston; *e*, the connecting-rod; *f*, f_1, the two-to-one pinion and gear, by means of which the cam-shaft is driven and the inlet and exhaust valves are operated; f_2, Fig. 14, the pulley for driving the fan that supplies a current of air for cooling the water-jacket circulating water; f_3, Fig. 14, a housing over the gears *f* and f_1; *g*, *g*, *g*, partitions to prevent oil from flowing to one end of the crank-case while running up or down hill; *h*, h_1, the inlet and exhaust valves, respectively; *i*, the intake pipe, a plan view of which is shown in Fig. 16, which also shows part of the exhaust header i_1 and the yokes i_2 that hold the inlet and exhaust pipes in place (in Fig. 14, the exhaust header is represented by dotted lines in order that other parts might be shown); i_3, the setscrew for fastening the intake pipe; *j*, j_1, screw plugs in threaded openings through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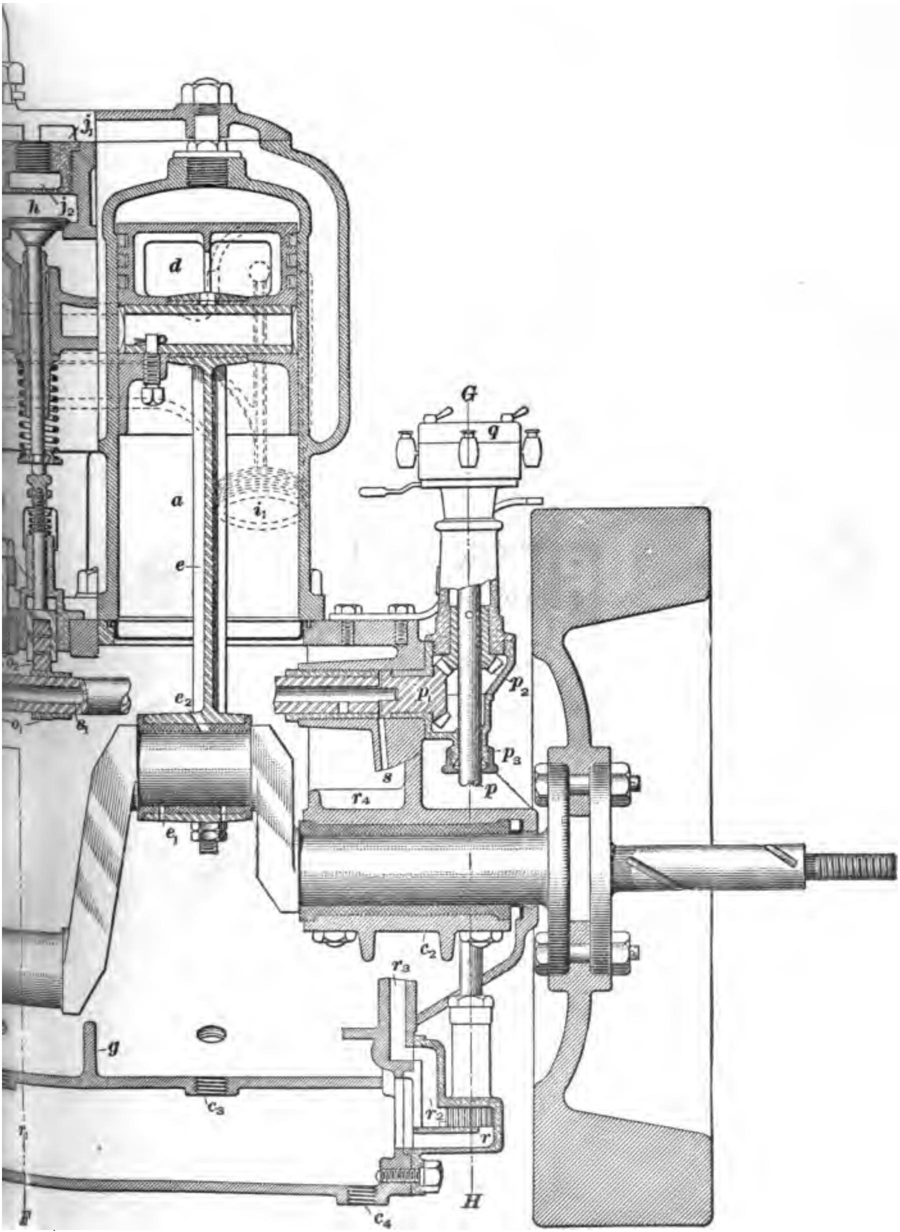
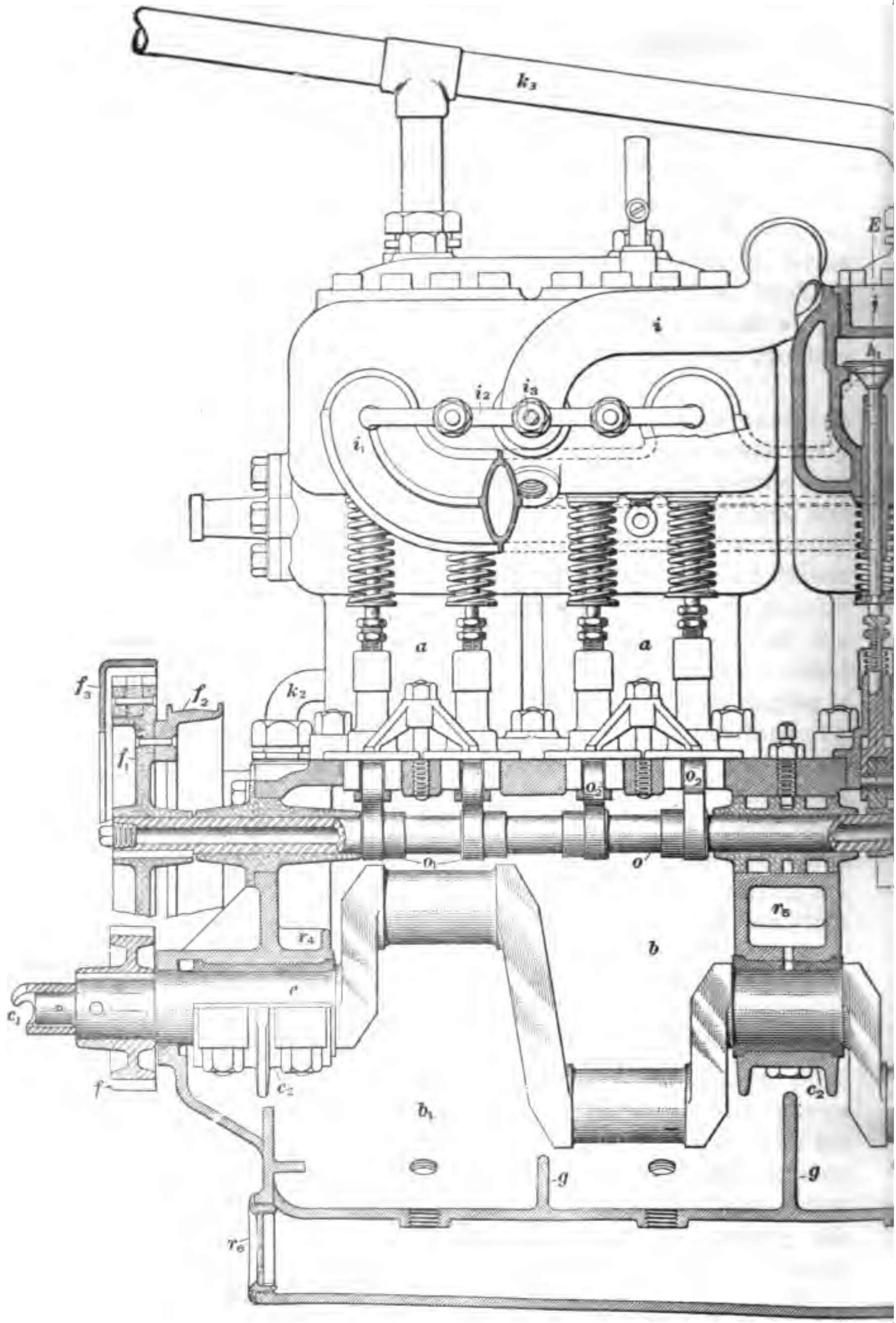


G. 14



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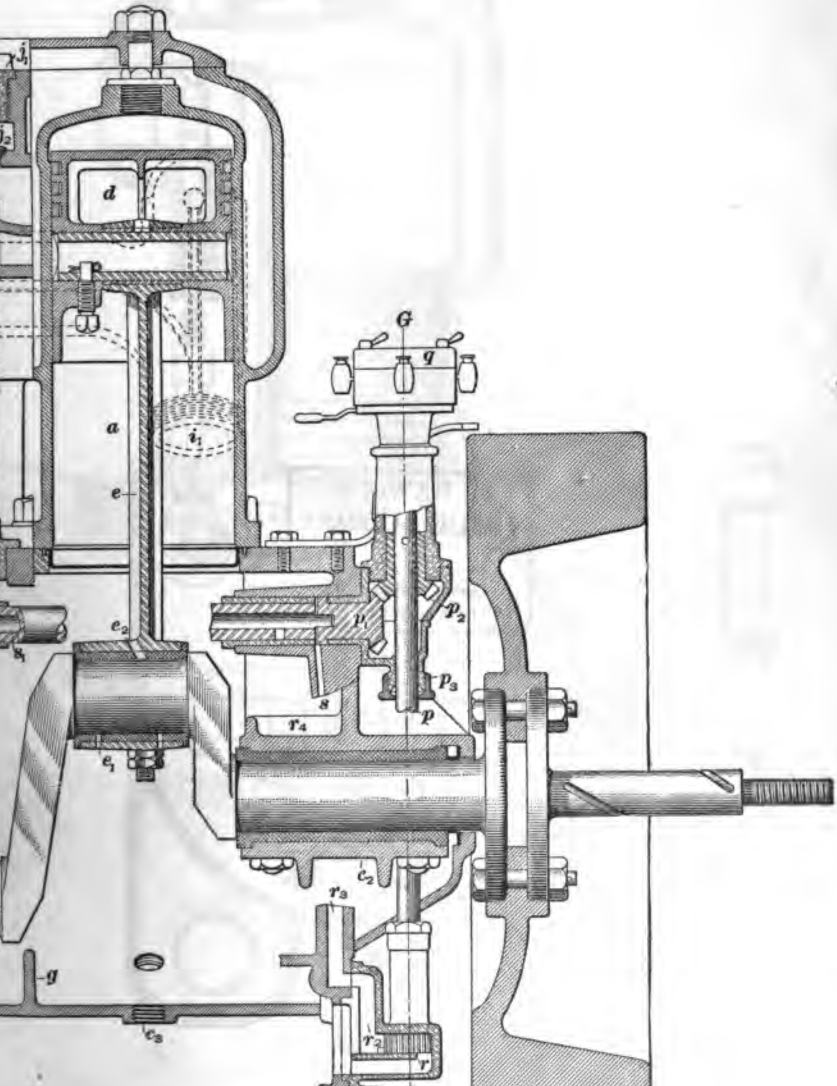

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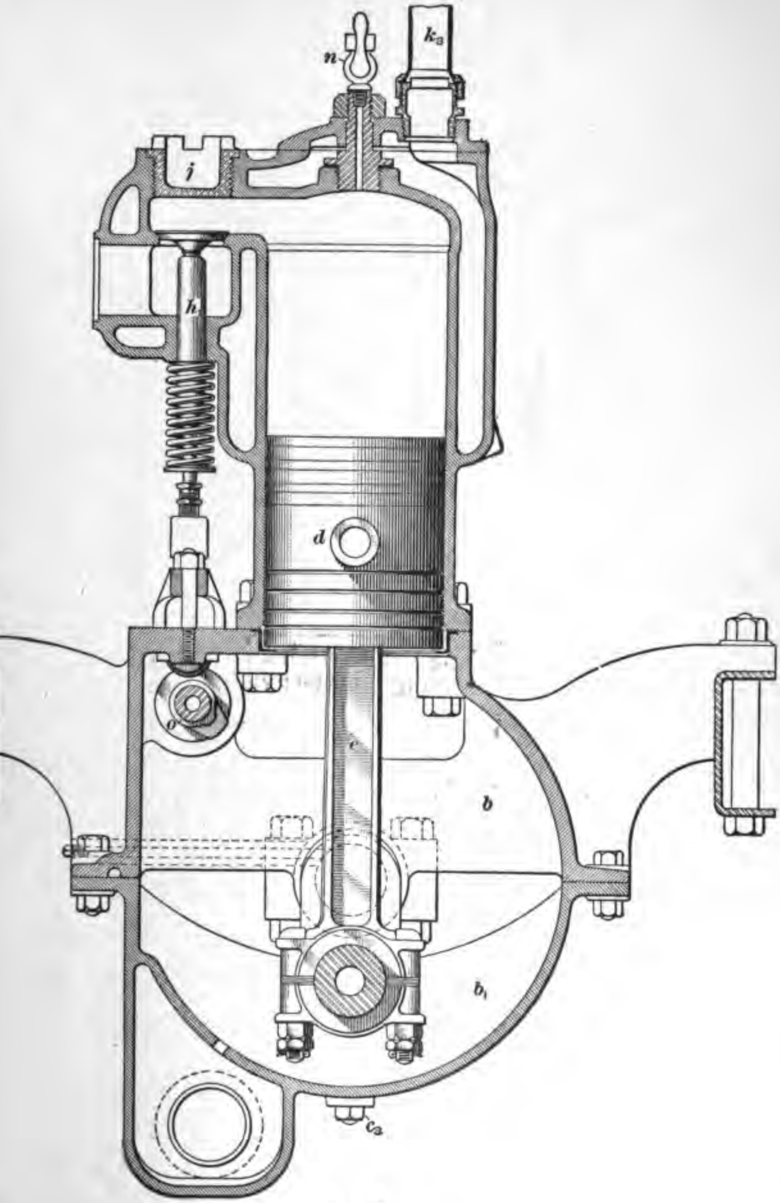


FIG. 15

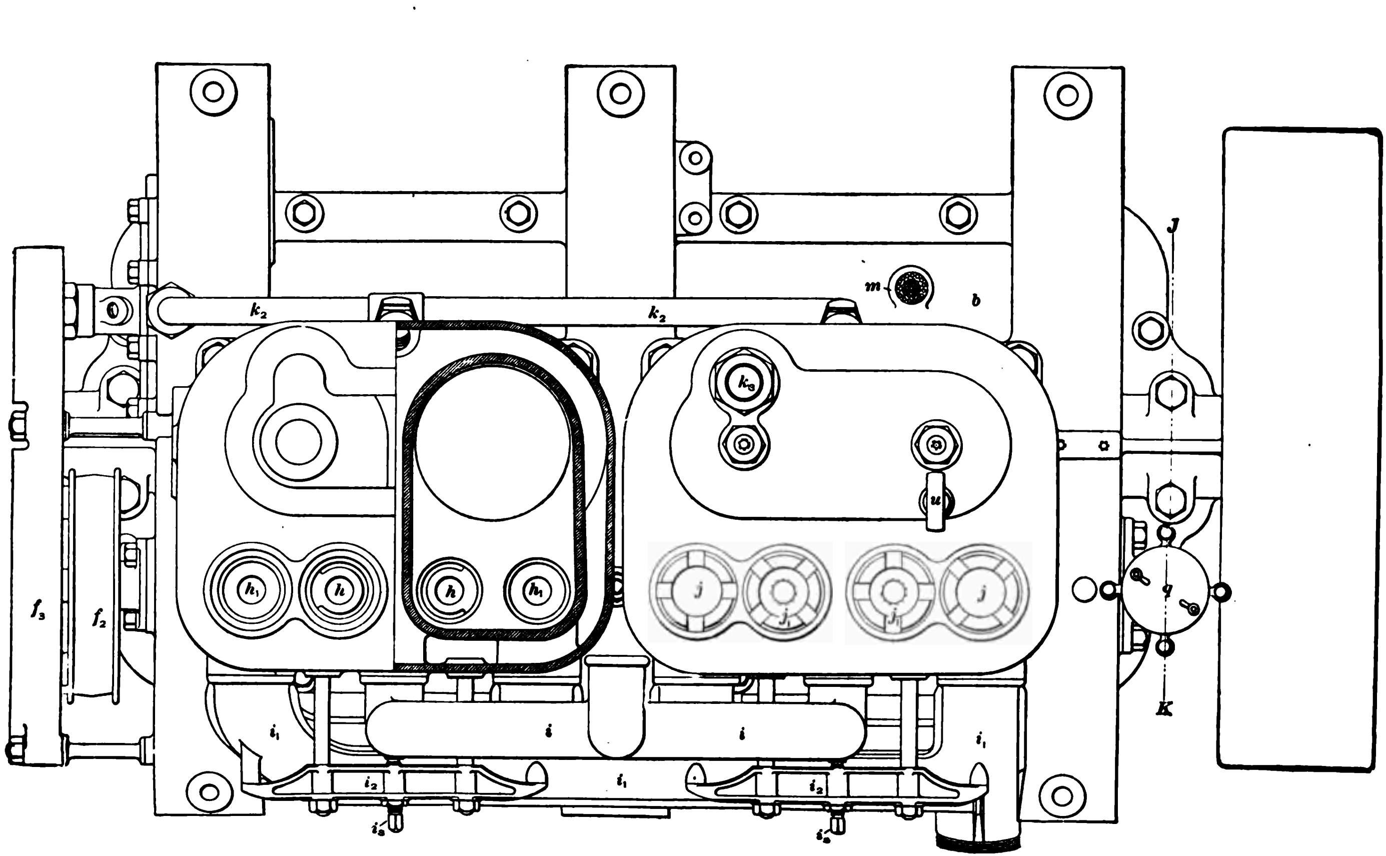


FIG. 16

which the exhaust and inlet valves may be removed for cleaning or repairs; j_2, Fig. 14, the spark chamber in the plug j_1 over the inlet valve (the spark plug, which is not shown, is screwed into j_1, and the chamber j_2 communicates

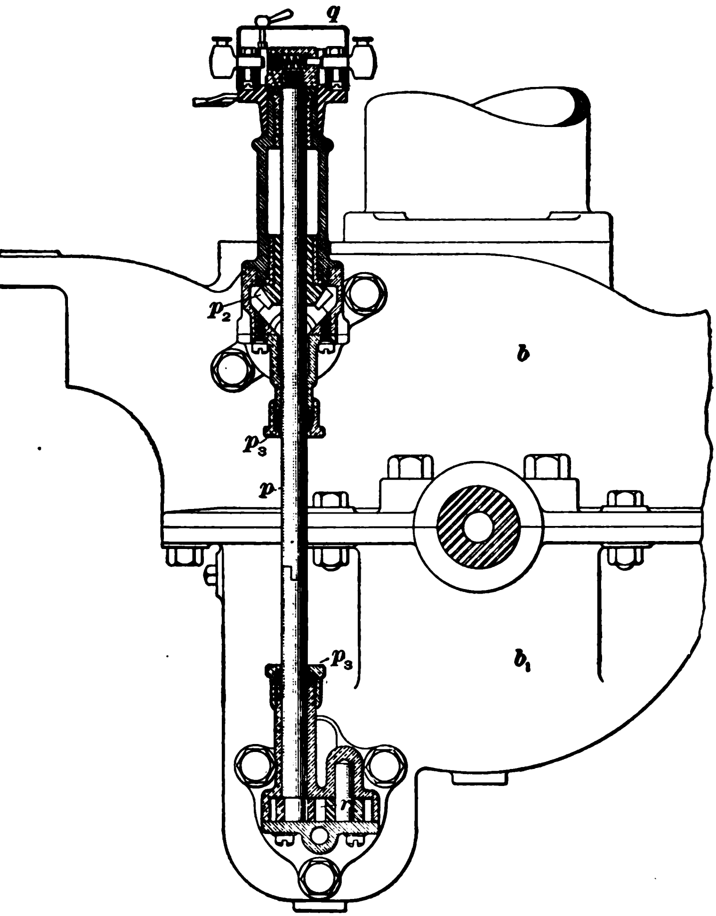


FIG. 17

with the combustion chamber through small holes in the thin bottom of j_1, the holes permitting the fresh mixture to reach the spark plug on the compression stroke, and allowing the flame to strike through and ignite the charge, but

preventing oil from reaching the spark plug); *k*, Fig. 13, the geared water-circulating pump; k_1, the stuffingbox of the pump; k_2, the water-pipe connection from the pump to the water-jackets, shown in plan in Fig. 16; k_3, the water connection from the top of the water-jackets to the radiator provided for cooling the circulating water; k_4, Fig. 13, the water connection from the cooling radiator to the pump; *l*, Fig. 13, the union for attaching the pipe from the carbureter (not shown) to the inlet header *i*; *m* (shown in elevation in Fig. 13 and in plan in Fig. 16), a crank-case vent pipe closed by a wire screen at its upper end and provided so as to permit oil to be poured into the crank-case and as a means of escape for the gases that leak past the pistons into the crank-case; *n*, Fig. 15, a compression relief cock; *o*, the cam-shaft carrying the cams o_1, Fig. 14, with which the push-rod rollers o_2 are always in contact; *p*, a shaft carrying the timer (a device by means of which the time of producing the spark in each of the cylinders is regulated); p_1, p_2, miter gears for driving the shaft *p*; p_3, Fig. 17, stuffingboxes; *q*, the spark timer; *r*, the rotary force-feed oil pump, the intake to which is protected by a wire screen. The means for attaching the timer and the oil pump to the crank-case is shown in Figs. 16 and 17, the latter figure being a sectional view taken along the line *J–K* of Fig. 16.

15. The lubricating system of this engine is somewhat distinctive. The oil pump *r* takes oil from the oil well r_1, Fig. 14, at the base of the crank-case and forces it upwards through the drilled passages r_2, r_3 (partly broken away) to the large pockets r_4, r_5 over the main bearings of the crank-shaft. A portion also goes up to the cam-shaft bearing *s*, where it passes, by way of suitable holes drilled in the shaft, to an oil passage s_1 running the entire length of the shaft. From this passage, it escapes to the three bearings by radial holes drilled in the shaft. The outer ends of the main bearings have oil retainers and return passages, by which oil working out to the ends of these bearings will return to the crank-case.

glass sight feed r_6 indicates the height of the oil in he oil well. The crankpins are oiled through holes e_1, e_2 rilled in the bottom caps and also in the top. Drainage lugs c_3, c_4 permit the oil to be drawn off from the crank-case nd also from the oil well.

16. Fig. 18 shows one pair of cylinders of a four-cylinder our-cycle vertical water-cooled automobile engine of French nanufacture, and adapted to use either alcohol or gasoline

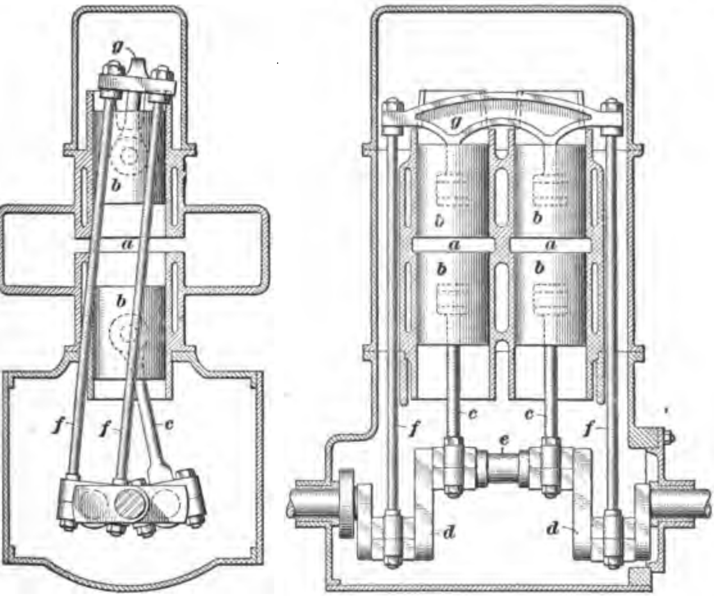


Fig. 18

or fuel. Each of the four cylinders a has two pistons b, etween which the explosions take place, driving the pistons part, one upwards and the other downwards. The two pper pistons in each pair of cylinders rise and fall together, is do the two lower pistons, which are connected by rods c of the usual type to a single crank d having a long crankpin e. The connecting-rods f for the upper pistons extend upwards to a common yoke g, to which they are rigidly secured. The outer ends of the yoke extend beyond the cylinder walls;

each end carries a connecting-rod, which extends downwards, outside the cylinder walls, and works on a crank set opposite the crank on which the lower connecting-rods work. When an explosion takes place between the two pistons in each cylinder, the lower piston drives downwards on its crank, while the upper piston pulls upwards on its crank, thus imparting a balanced action, which is said to contribute largely to the smooth running of the engine. Each pair of cylinders is enclosed in a casing that is large enough to include the long outside connecting-rods *f* and the yoke for the upper pistons, so that the moving parts are all enclosed. The valves are so placed that the inlet and exhaust ports open into a combustion chamber between the two pistons. The inlet and exhaust valves are mechanically operated, and are placed on opposite sides of the cylinders. The cylinders are cast in pairs. Fig. 18 shows only two of the four cylinders, or half of the engine, the other half being, of course, exactly the same.

AIR-COOLED AUTOMOBILE ENGINES

17. The successful air cooling of an engine cylinder depends chiefly on an abundant flow of cool air over it. Some cylinders, however, are arranged to utilize a more rapid flow than others. Generally speaking, the designer can take his choice between a comparatively plain cylinder surface over which a current of air can flow almost unchecked, and a cylinder with its heat-radiating surface greatly multiplied by numerous pins, deep ribs, or other projections. These projections increase greatly the radiating surface, but tend to obstruct the flow of air, although they aid in carrying away the heat. In the latter case, the velocity of the air stream does not need to be high, provided it is continuous; while in the former case, a constant and abundant supply of air is essential. In either case, it is necessary that a reasonable percentage of the air shall make actual contact with the heated metal, the remainder of the air coming into service to dilute the portion heated by contact, and therefore to

eep it cool enough for further effective service. The problem is to supply a sufficiently extended cylinder surface and sufficiently large volume of air, with a given velocity of ow at the cylinder surface, to make certain that the required mount of heat will be transferred from the cylinder to the ir to keep the cylinder comparatively cool. As the volume f the air used for cooling is far greater than that of the vater that would be employed for the same purpose, and as he specific heat of air is less than that of water, it is obvious hat a correspondingly greater velocity of flow will be required or air than is necessary for water. Calculation shows that or efficient cooling, the air supply should not be less than 0 cubic feet per minute per horsepower of the engine. If he air is not so directed as to be effective in cooling the ngine cylinder, it will be necessary to supply a greater uantity.

18. One manufacturer's method of increasing the heat-adiating surface of the cylinder of an air-cooled engine consists in thickly studding the surface of the cylinder with small ins $\frac{7}{32}$ inch in diameter, each projecting for a length of inches. In order to add considerably to their surface at mall expense, the pins are threaded over their entire length, nd are screwed into the cylinder walls to a depth of $\frac{1}{8}$ inch. ach pin is calculated to have an exposed surface of .3 square inches, and, since the average number of pins is ine per square inch of cylinder surface, the heat-radiating urface is multiplied nearly thirty times. The engine with hich this method of cooling the cylinders is employed is ung horizontally lengthwise under the body of the automobile, and is placed somewhat low, so that it receives a ood current of air whenever the motion of the vehicle is apid. The effectiveness of the current is increased by mall fans placed so as to blow directly on the cylinder eads. Although the pins are set together so closely that he velocity of the air stream through them must be somewhat low, this method of cooling is found so effective that he cylinders are made in sizes as large as 5 inches bore.

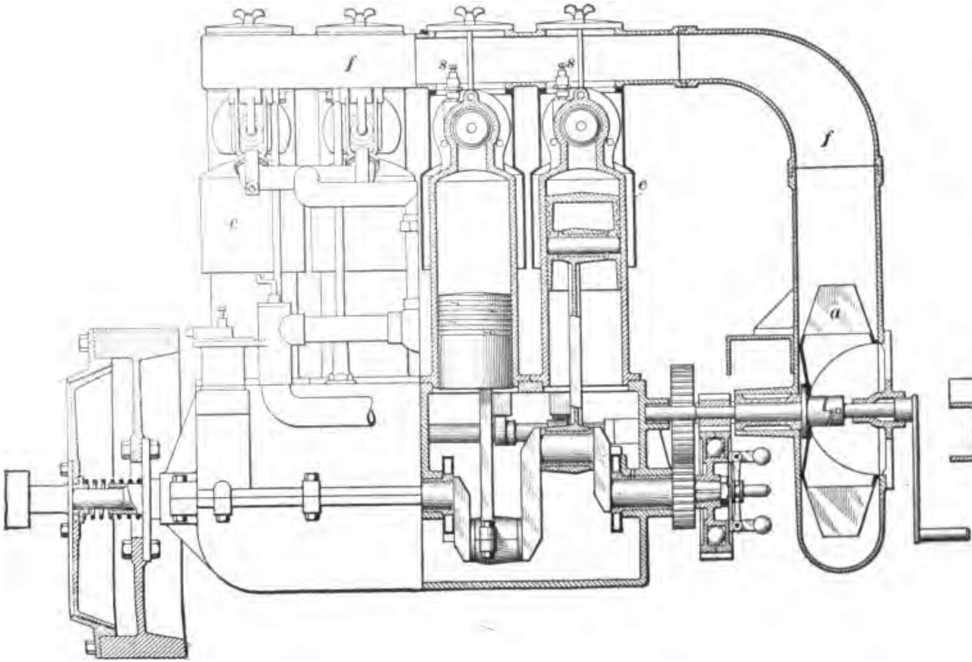


FIG. 19

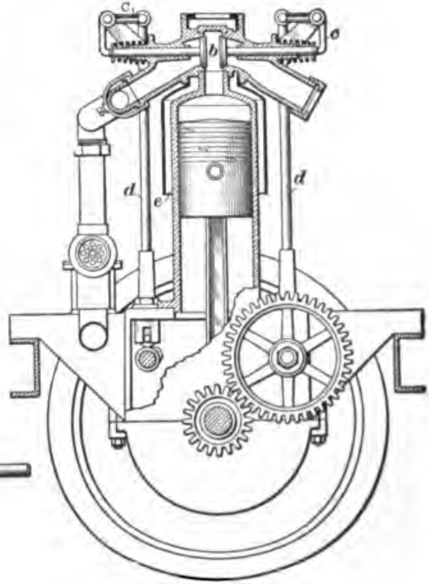


FIG. 20

19. One method of cooling engine cylinders by convec-
on is shown in Figs. 19 and 20. A centrifugal blower *a* is
rranged at the front end of the engine and run by gears at
bout three and one-half times the speed of the engine,
orcing a strong blast of air under a pressure of about
ounces per square inch to the head of each cylinder and
ownwards around the cylinder walls. The inlet and exhaust
alves work horizontally, opening into a small valve cham-
er *b* at the extreme top of the cylinder head. They are
pened by bell-cranks *c* and push rods *d*, Fig. 20. As indi-
ated by Fig. 21, the cylinder walls are studded externally

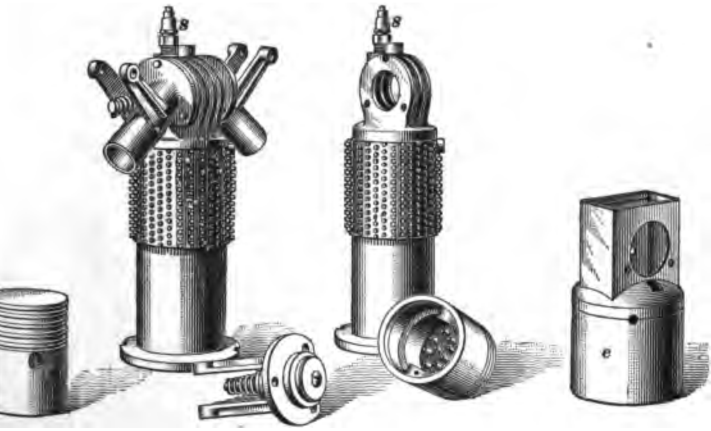


Fig. 21

vith small pins, $\frac{1}{4}$ inch long and $\frac{1}{8}$ inch thick, cast on the
ylinder. Around each cylinder is a light aluminum housing *e*
hat holds the air stream close to the cylinders. The housings
re open at their lower ends, and at their upper ends connect
vith an air pipe *f*, Fig. 19, that conveys the air from the
lower. The air pipe is of tapering cross-section, the small
nd being that farthest from the blower. The spark plugs *s*,
'ig. 21, screw into the extreme top of the cylinder heads and
roject upwards into the air pipe, which keeps them cool.
'he electrical connections for the spark plugs are carried
hrough the air pipe. With this method of cooling, from 70
o 80 cubic feet of air per minute per horsepower is required.

20. A popular type of four-cylinder vertical air-cooled engine, in which the heat-radiating surface is increased by the use of thin horizontal flanges cast on the cylinder, is shown in Fig. 22. The inlet and exhaust valves are mechanically operated, and open directly downwards into the cylinder heads, which are cooled by the same kind of horizontal flanges as the cylinder walls. The valves have short stems, and are actuated by rocker-arms and push rods, as shown. Small engines of this sort, up to about 12 or 16 horsepower, are mounted crosswise under a bonnet at the front of the automobile, and are cooled solely by its motion. The cylinders of such motors are always small, never exceeding 4 inches bore, generally being less. In order to prevent overheating in the combustion chamber, the compression is made somewhat low, especially when the bore is larger than 3½ inches. The engine illustrated is arranged to lie fore and aft, or lengthwise, and is cooled by the large belt-driven fan shown. This arrangement is open to the objection that the current of air from the fan must lose much of its effectiveness before it reaches the farthest cylinder. Nevertheless, it is found on several automobiles of from 16 to 20 horsepower, and apparently gives fair results in cooling the cylinder.

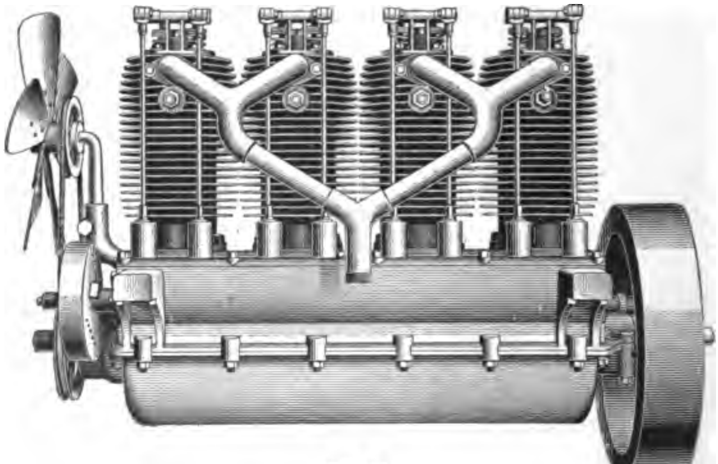


FIG. 22

21. Another form of the air-cooled type of engine is shown n **Fig. 23.** In this engine, the inlet and main exhaust valves are located in the cylinder head, and are mechanically

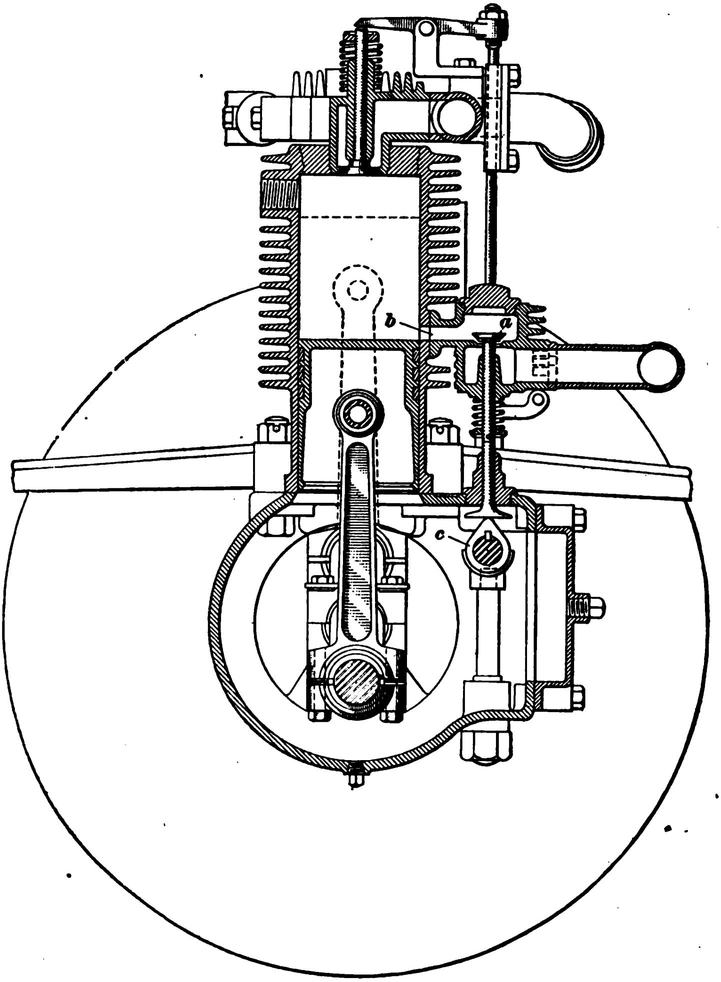


FIG. 23

operated in the usual way. The special feature that distinguishes this engine from the ordinary air-cooled engine is an auxiliary cylinder exhaust controlled by the valve *a* and

by the movement of the piston, which uncovers the port *b* near the end of the expansion or working stroke. The object of the valve *a* is to prevent the gases in the exhaust pipe from being drawn back through *b* on the suction stroke, in case the throttle should be partly closed. This valve is opened by the cam *c* just as, or before, the piston passes the upper edge of the auxiliary exhaust port, and closes when the piston has reached the end of its stroke.

The special advantage of the auxiliary cylinder exhaust for an air-cooled motor is that it gets rid of from two-thirds to three-quarters of the exhaust gas at a point quite remote from the cylinder head, where, of course, the highest temperatures are found. As the problem of cooling a cylinder by air is mainly to cool the hottest parts, that is, the cylinder head and the exhaust valve, the advantage of the arrangement shown is at once obvious. By insuring low temperatures at these critical points, it makes possible higher compression and higher motor speeds.

OIL ENGINES

AUTOMOBILE AND MARINE TYPES

22. Engines burning kerosene and crude oil are classed together as oil engines. With practically but one exception, the Diesel engine, kerosene is the fuel used. The risk connected with the use of gasoline as a fuel, particularly for portable engines, is absent in kerosene engines, because of the fact that this oil does not give off inflammable vapors at ordinary temperatures. On the other hand, the characteristics of the fuel necessitate several special features in the engines, and it has been found a matter of considerable practical difficulty to produce engines that will burn kerosene with the same degree of ease and simplicity that attend the use of gasoline.

23. The flashing point of kerosene, or the temperature at which it gives off inflammable vapor, is 150° F. for

rdinary lamp oil; but there are grades that give off vapors t temperatures a little above or below this. In the liquid ate, kerosene is not inflammable, and it will, in fact, extin-uish a lighted match or taper plunged into it. It is only e vapor of kerosene that is inflammable, and to produce is vapor heat must be supplied. When heated kerosene is vaporated at a temperature not above its boiling point it aves little or no residuum. If, however, the vapor is ubjected to a higher temperature, it is decomposed, or split p into lighter hydrocarbons, and leaves behind a portion of e carbon in the solid state. Kerosene vapor condenses asily on any cold surface, but if the vapor is passed rough a red-hot pipe, it does not condense as readily. Numerous devices for heating kerosene have been tried, ome experimenters using an independent flame under a coil f pipe, others using the heat of the exhaust gases. Many f these devices have been quite successful, but in all of em there is the necessity of cleaning the vaporizing coil t intervals, owing to the apparent impossibility of other-wise maintaining exactly the right temperature under all ircumstances.

24. Bearing in mind the peculiarities of kerosene as fuel, e various devices employed to utilize it may be divided nto three classes, as follows: (1) those in which the oil is asified by heat before it enters the cylinder; (2) those in which liquid oil is sprayed into the combustion chamber and asified by the hot and unjacketed walls of the cylinder ead; (3) those in which the kerosene is sprayed into the ir stream by a vaporizer or carbureter somewhat similar to hose used with gasoline, and vaporized by heat and com-pression after entering the cylinder.

On the face of it, the first method would seem to be the ost logical, as it enables the air and vapor to be much more thoroughly mingled than by the other methods, a condition that obviously increases the efficiency of the engine. Against this must be set the difficulty, already mentioned, of maintaining the proper temperature for the vaporizing coil.

Besides this, there is the difficulty that under ordinary conditions the kerosene vapor condenses when cooled below the flashing point of the oil, so that the entering charge is not a perfect mixture of air and gas, but a stream of air carrying with it an extremely minute spray of oil, and the only way to overcome this difficulty is to heat the air to such a degree as to decrease the economy. It does not appear impossible, however, that successful engines of this class will be produced, especially as experiments seem to indicate that the kerosene vapor, if mingled with a certain small amount of air while still hot, may be made to partake more or less of the properties of a fixed gas, so that trouble due to condensation is avoided.

25. In most oil engines, at least in America, a few drops of liquid kerosene is injected into the combustion chamber, or into a heated chamber connected with the combustion chamber, where it is vaporized. The most representative engines of this type have an unjacketed cylinder head made separate from the walls. The head is bolted to the cylinder with an asbestos gasket between the head and the cylinder so as to retard the flow of heat to the cylinder walls and thus keep the head hot. The engine is so designed that the piston comes practically to the end of the cylinder, so that the combustion chamber is formed in the head, and is therefore cup-shaped in form. Usually, the head is not perfectly plain on the inside, but contains ribs projecting into the combustion space and generally separate from the cylinder head, the better to retain the heat. At either the suction or the compression stroke, the oil is sprayed by a pump on the heated inner surfaces, where it is immediately gasified. As the compression stroke proceeds, air is compressed into the combustion chamber, where it mingles with the oil vapor. In all engines of this class, ignition is spontaneous, being produced by the combination of high temperature and pressure when the compression stroke is nearly completed. Owing to the temperature of the ribs and head, any carbon deposited is burned. The engine is usually started by heating the

ylinder head with an external flame, but sometimes the ngine is started on gasoline and is changed to kerosene vhen the cylinder head becomes hot.

A modification of the construction just described, enabling he ignition to be more accurately timed, is to make the ylinder head flat instead of dished, and to concentrate the eat necessary for ignition in a small extension bolted to he head and carefully screened to shut off radiation. The nternal ribs mentioned are dispensed with, and the charge s fired when a portion of it has been compressed into this eated chamber, which, in effect, combines the functions of asifier and igniter.

26. In the third type of engine, the oil is treated nearly s if it were gasoline. It is sprayed into the air from a aporizer or carbureter, and the only important difference s that heat is added, either at the carbureter or at the point of entrance to the cylinder, to vaporize the cold spray.

AUTOMOBILE KEROSENE ENGINE

27. In Figs. 24 and 25 is shown a form of automobile kerosene engine. The principal difference between this engine and the gasoline engines already described lies in the means employed for vaporizing the fuel. A carbureter of ordinary form is piped up through a two-way cock and branched pipe, one branch passing to a kerosene tank and the other to a small gasoline tank. From the carbureter the mixture is taken through an ordinary throttle valve to a hot vaporizer *a* in a chamber *b* between the inlet valve *c* above and the exhaust valve *d* below. This hot vaporizer is made of a high-carbon machine steel, and is soft and cylindrical. It has a $\frac{3}{8}$-inch axial hole through a central core, having radiating disk flanges or circumferential ribs of $\frac{11}{32}$-inch pitch. The valve chamber *b* opens to the cylinder *e* by a cored passage *f*, Fig. 25, in the cylinder head. The incoming charge sweeps over and about the top half of the vaporizer, and the exhaust shoots over the top of the vaporizer and down each side of it. The spark plug is horizontal, being screwed into

the outside wall of the valve chamber at *g*, Fig. 25, where the spark points are swept by the hot exhaust.

To heat the vaporizer, a $\frac{3}{8}$-inch pipe is led from the opening passing through it to a $\frac{3}{8}$-inch hole *h*, Fig. 24, located

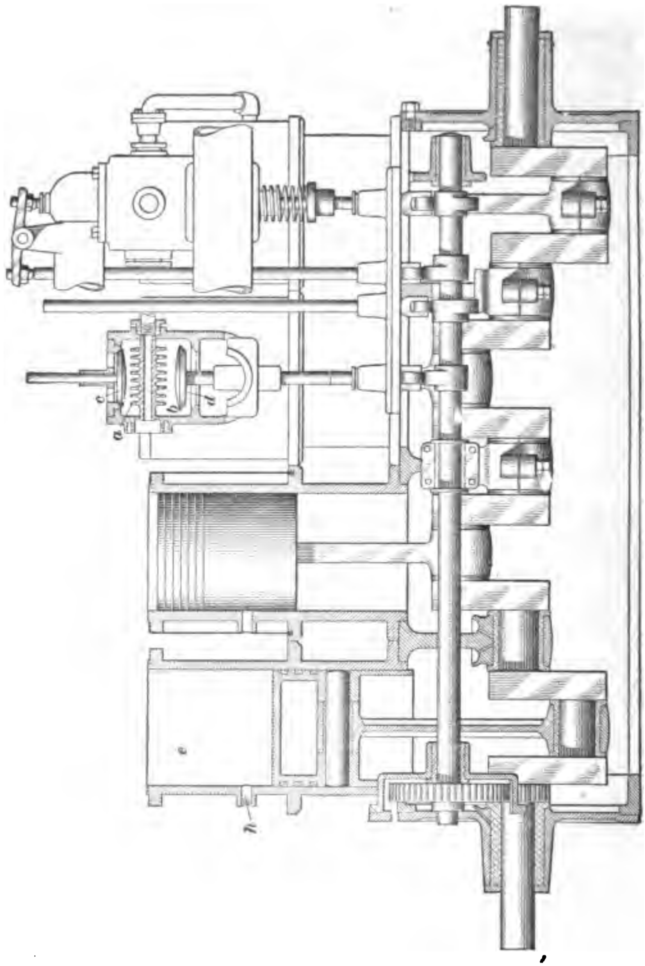


Fig 24

above the top of the piston when in its lowest position. As soon as the piston, in ending its working stroke, uncovers this $\frac{3}{8}$-inch hole, the first exhaust rushes through the $\frac{3}{8}$-inch

pe and the hole in the vaporizer, and thence to the muffler. he exhaust valve *d*, Fig. 25, begins to open at the same me that the piston begins to uncover the side-pipe exhaust the cylinder, and remains open until the piston reaches e top of the exhausting stroke, when the inlet valve *c* egins to open and the piston egins its intake stroke. The rbureter valve is adjusted trial to give the maximum ake horsepower at 600 rev- utions per minute and is ot subsequently changed. soline is used as an initial arge for starting, after hich a branch-pipe cock is rned to the kerosene supply. fter the charge passes the rottle, it sweeps past the ot vaporizer as the piston cks the charge into the linder, and finally, after mpression, the charge is red by an electric spark.

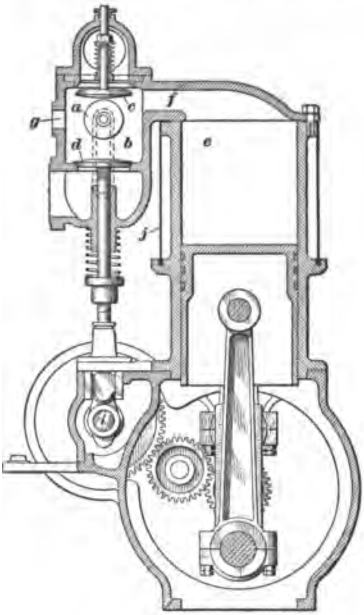


FIG. 25

The cam-shaft *i* is all en- osed, and the oiling is done a force pump.

The water-jackets *j* are of drawn copper, flanged at the p and pinched between the tops and heads of the cylinders. he lower ends of the jackets have expansion heads, and are nned and fixed in the cylinder-flange grooves by filling the tter with molten lead and calking them around the outside.

MARINE KEROSENE ENGINE

28. Fig. 26 shows, with some details omitted, a kerosene arine engine that works on the two-stroke cycle, and in hich the fuel is injected by a pump during the compression troke. Here, *a* is the cylinder; *b*, the crank-case; *c*, the ater-jacket; *d*, the cylinder head; *e*, the piston; *f*, the

connecting-rod; *g*, the exhaust port; *h*, the transfer port; *i*, the deflector; *j*, the pipe carrying the fuel oil from the oil pump (not shown); *k*, an oil cup for one of the main bearings; *l*, a groove in the connecting-rod by which oil splashed in the case is caught and fed to the crankpin; and *m*, the crank-case air inlet, which is uncovered by the lower edge of the piston when near the top of its stroke. The air so entering is retained on the down stroke, and is transferred to the cylinder by the uncovering of the port *h* after the exhaust port has been opened. As the piston goes up, the oil is injected, striking the triangular lip *n* projecting from the base of the hot ignition chamber *o*. The oil is vaporized by the heat, and a portion of the mixture is compressed into *o*, where it ignites spontaneously near the end of the compression stroke. The igniter ball is kept hot by the jacket *p*, and is heated for starting by the burner *q*. When the burner is working, the cover of the jacket *p* is removed. The engine is regulated by a centrifugal governor not shown, the governor varying the amount of oil injected.

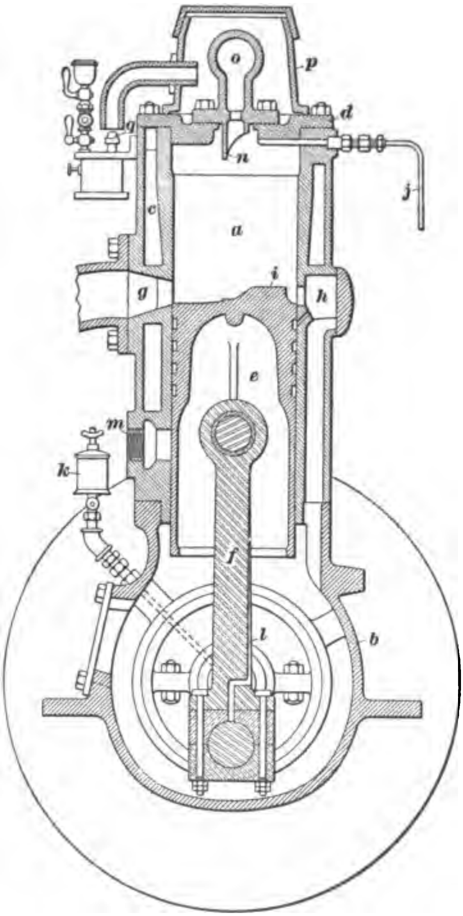


FIG. 26

TWO-CYCLE GASOLINE ENGINES

TWO-CYLINDER TYPES

29. Referring to Figs. 27 and 29, a sectional side elevation and a plan section respectively of a typical two-cylinder

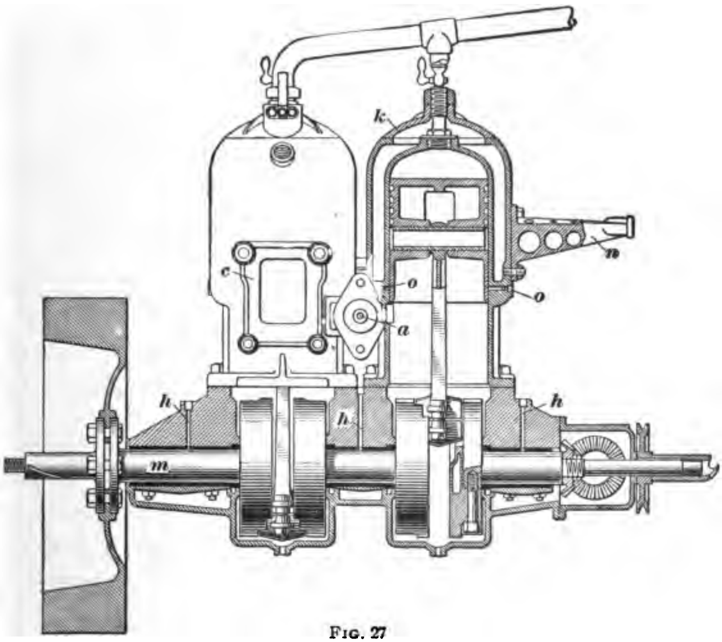


Fig. 27

two-cycle engine, *a* is the inlet opening to which the carbureter is attached and through which the gases enter the cylinders below the pistons and pass into the crank-case through the port *b*, Fig. 28. This opening is formed in a triangular piece fitting in the angle between the two cylinders. On the inlet side of the cylinder is a pair of plates *c* and *d*, Figs. 28 and 29, forming the outside of the by-pass

channel through which the mixture passes from the crank-case to the cylinders above the piston. As indicated in Fig. 28, *d* is a sloping plate that aids in directing the gases into the combustion chamber, the entire passage *e* through which the gases pass from the crank-case being visible. Fig. 29 shows the by-pass channel *e*, as well as the openings *b'* in the cylinder wall through which the gases pass into the cylinder; also, the bridge *f* separating these openings. The bridge is used to keep the piston rings in position, as a continuous opening of the circumferential length of the two openings *b'* would permit the rings to expand into them as the piston moves back and forth. Early designers of two-cycle engines made these inlet ports smaller than at present, and avoided the bridge.

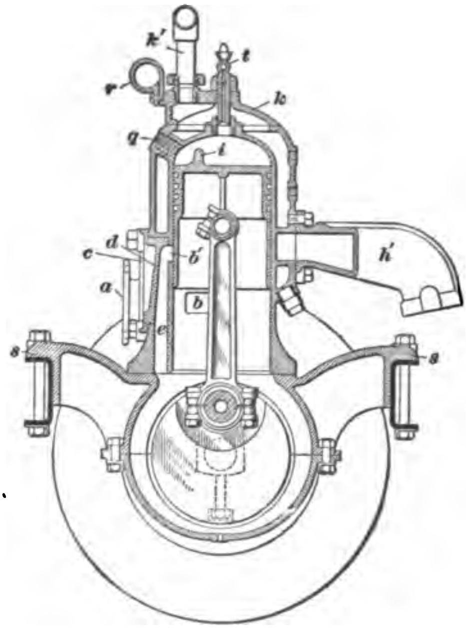


FIG. 28

At the exhaust side of the two cylinders, there are two oblong openings *g*, in the sides of the cylinder to which the exhaust pipes *h'*, *h'*, Fig. 29, are secured. These ports *g* are separated by a central vertical bridge *g'*, and, as shown in the figure, the ports are larger in circumferential measurement than the inlet ports, and their height is slightly greater. They are located at nearly the same distance from the top of the stroke as the inlet ports. The deflecting plate *i*, Fig. 28, on the top of the piston is carried close to the inlet side, in order that the inrushing mixture may be directed toward the cylinder head,

and not cross the cylinder space and pass out through the exhaust port.

30. Cooling a two-cylinder two-cycle engine requires much more water and air circulation than a four-cycle engine, because the explosions take place twice as often and there is double the heat generated. Water circulation in the engine here described is maintained by a pump *j*, Fig. 29, at the left of the engine. The water enters each water-jacket immediately below the exhaust port, and leaves from the head-cap *k*, through the pipe *k'*, Fig. 28. The pump *j* and the spark timer, or commutator, *l*, Fig. 29, are

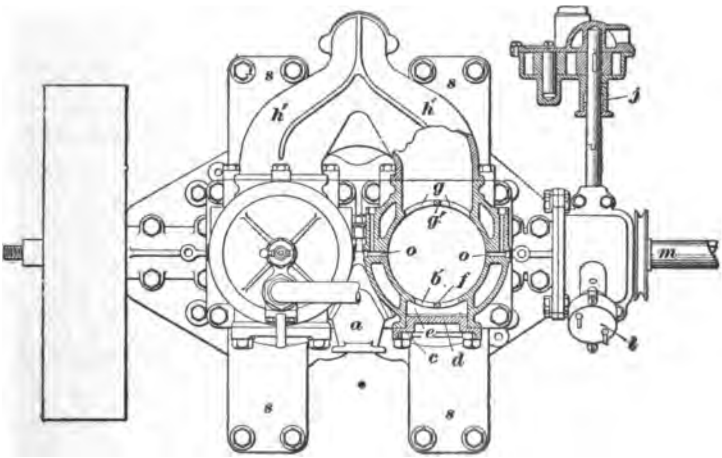


FIG. 29

driven from the crank-shaft *m*, the pump by a horizontal shaft extending to the right and the commutator by a similar shaft rising obliquely to the left. Both shafts are driven by bevel gears enclosed in a suitable housing. This arrangement of the pump and commutator places them in most accessible positions. A radiator of flat vertical tubes and a belt-driven fan supported on a bracket *n*, Fig. 27, from the forward cylinder are provided for cooling the circulating water.

31. Explosions at each revolution of the crank-shaft call for additional lubrication as well as cooling. Oil is fed into

opposite sides of each cylinder through ducts *o*, *o*, Fig. 29. Connecting with these ducts are holes, or leads, from a force-feed lubricator. Similar leads *h*, *h*, *h*, Fig. 27, supply oil to the three bearings of the crank-shaft. The wristpins are clamped to the connecting-rods, giving them a bearing in both sides of the piston and facilitating lubrication, the oil flowing into the bearings from the cylinder walls. There is little room for an oil bath in the crank-case, but there is sufficient oil to maintain a splash that aids in lubricating the lower portions of the cylinder walls.

32. The spark plugs are screwed into the threaded openings *q*, Fig. 28, in the cylinder heads, giving them an angular position. A support *r* on the cylinder heads holds the electric wires led to the plugs. The engine is self-starting. The main, or crank-shaft, bearings are arranged in the upper half of an aluminum crank-case supported by integral lateral arms *s*. The bottom of the case is made as small as possible, to reduce the crank-case capacity; it also serves as an oil reservoir. Cylinders and pistons are of cast iron, the former machined down from the rough, ground to size, and then smoothed to a finish by running the pistons in them for several hours. On each piston are four piston rings; the wristpins are hollow, and are made of steel. The removable caps *k* on the cylinder heads allow of ready inspection of the water-jackets. The caps are held in place by hollow screws that carry priming cups *t*, the gasoline passages being through the screws. The crank-shaft is a drop-steel forging subjected to a special heat treatment, and is machined, ground to size, and carefully balanced; phosphor-bronze bushings are used on the crank-shaft and in the connecting-rods, which are drop forgings.

33. Inasmuch as there is an explosion in each cylinder of a two-cylinder two-cycle engine for each revolution of the crank-shaft, while in four-cycle engines there is an explosion in each cylinder for every two revolutions of the crank-shaft, it is evident that a two-cylinder two-cycle engine when running at a given speed gives as many explosions, or useful

strokes, as a four-cylinder four-cycle engine operating at the same speed. Hence, the power developed in each cylinder of a two-cycle engine is approximately double that generated in each cylinder of a four-cycle engine of the same size.

FOUR-CYLINDER TYPES

34. In Figs. 30 and 31 is shown a four-cylinder two-cycle engine of the three-port type. Each of the four cylinders *a* is cast separately, and is bolted to a one-piece

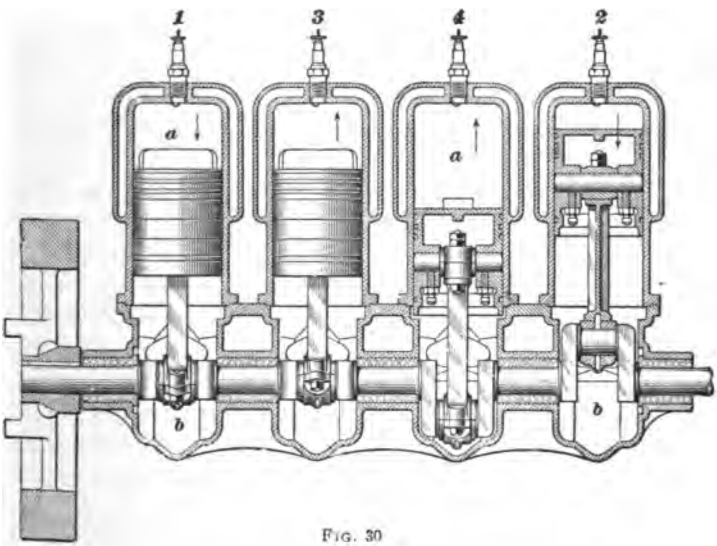


FIG. 30

crank-case *b* having for each crank a separate air-tight compartment, on both sides of which are handholes covered with aluminum plates bolted in place. Facing the flywheel, the crank-case inlet ports *c*, Fig. 31, are at the left side of the cylinders, and are connected to the carbureter by means of an inlet manifold having four throttle valves—one for each cylinder. The transfer, or passover, passages *d* through which the charge passes from the crank-case to the cylinders, are cast in the latter at the right and are covered by plates *e*, a wire gauze and a perforated sheet-metal screen *f*

being placed in the transfer passage to prevent back firing Fig. 31, which is not a cross-sectional drawing of the actua engine, is shown simply to illustrate in a general way the arrangement of the ports, which do not appear in the longitudinal section, Fig. 30. As indicated by Fig. 31, the exhaus gases are discharged through the ports *g* to a cast-iron manifold bolted to the left side of the cylinders. The engine is lubricated by means of a force-feed oiling device driven by belting from a secondary shaft provided for operating the timer and water-circulating pump. The spark plugs are located in the center of the cylinder heads, as shown.

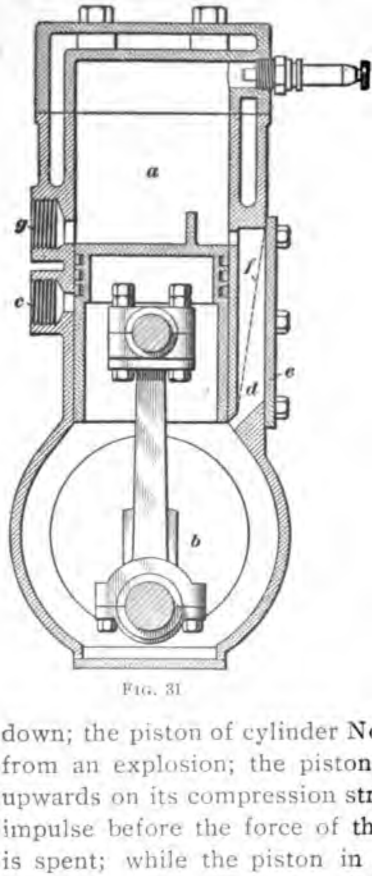


FIG. 31

As indicated in Fig. 30, the cranks are set 180° apart for each pair of cylinders, and the cranks of one pair of cylinders are set 90° from those of the other pair, the object being to secure a uniform unbroken application of power to the crank-shaft, the intervals between the power impulses being of exactly the same length. Referring to Fig. 30 an explosion in cylinder No. 1 has forced the piston half way down; the piston of cylinder No. *2* is just starting downwards from an explosion; the piston in cylinder No. *3* is moving upwards on its compression stroke, and will receive its power impulse before the force of the explosion in cylinder No. 2 is spent; while the piston in cylinder No. *4* will receive a power impulse when the piston of cylinder No. *3* is half way through its power stroke.

MARINE GASOLINE ENGINES

CONSTRUCTIVE FEATURES

TWO-CYCLE ENGINES

35. Introduction.—So far as their essential features are concerned, there is little difference between automobile and marine engines. In fact, automobile engines are frequently installed in boats, and give satisfactory results in such service. A knowledge of the principles, operation, care, and management of the automobile engine is therefore quite essential for the running of automobile engines installed in boats. A thorough understanding of the conditions likely to be encountered in marine practice is also of benefit to the automobile engineer, for the intimate connection between the best types of marine and automobile engines is likely to become closer as the two-cycle engine, the use of which is now confined largely to marine practice, is further developed and adapted for use in commercial vehicles requiring comparatively low engine speed.

36. Single-Cylinder Types.—The two-cycle engine is so much simpler and cheaper and takes up so much less room than a four-cycle engine of the same power, that it is the most popular type of marine engine for small powers. As usually constructed, two-cycle engines can be operated in either direction of rotation, while a four-cycle engine requires the use of complicated reversing-valve motion, separate cams, etc., or a reversing gear, in order that the direction of rotation of the propeller shaft may be changed.

Two-cycle engines usually consume more fuel than four-cycle engines, but with small engines the increased consumption is not of great importance. With engines of from 10 to 100 horsepower, however, the consumption of fuel

is an important factor to be considered, and this is one of the reasons why large two-cycle engines are not often used for marine work.

On account of the warping to which a two-cycle engine cylinder is liable because of the varying temperatures and unequal expansion of the metal—the incoming gas being cold and entering at one side of the cylinder, while the exhaust, which is very hot, passes through a port on the opposite side—the cylinder is rarely made larger than 7½ inches in diameter, and never of that bore in multicylinder engines. In four-cycle engines, 10-inch bore is not unusual, and in some cases 12-inch cylinders have been built and used more or less successfully.

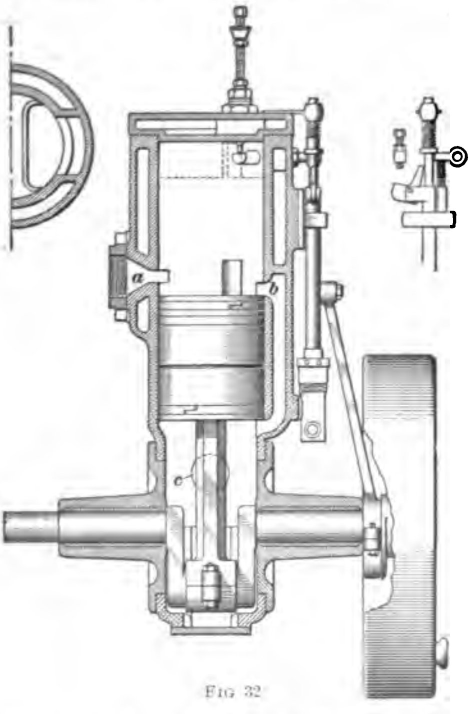


FIG. 32

37. There are two types of two-cycle engines: the two-port type and the three-port type, the latter being of more modern construction. Each type has its advantages and disadvantages. Fig. 32 is a vertical cross-section of a two-port engine in which *a* is the exhaust port, and *b* the inlet or pass-over port connecting the combustion chamber with the crank-case. The inlet and exhaust ports are opened and closed by the piston. The explosive mixture enters the crank-case through the opening *c* to which a check-valved supply pipe from the carbureter is attached.

38. In the three-port engine shown in Fig. 33, the cylinder *a* and the crank-case *u* are cast together, the water-

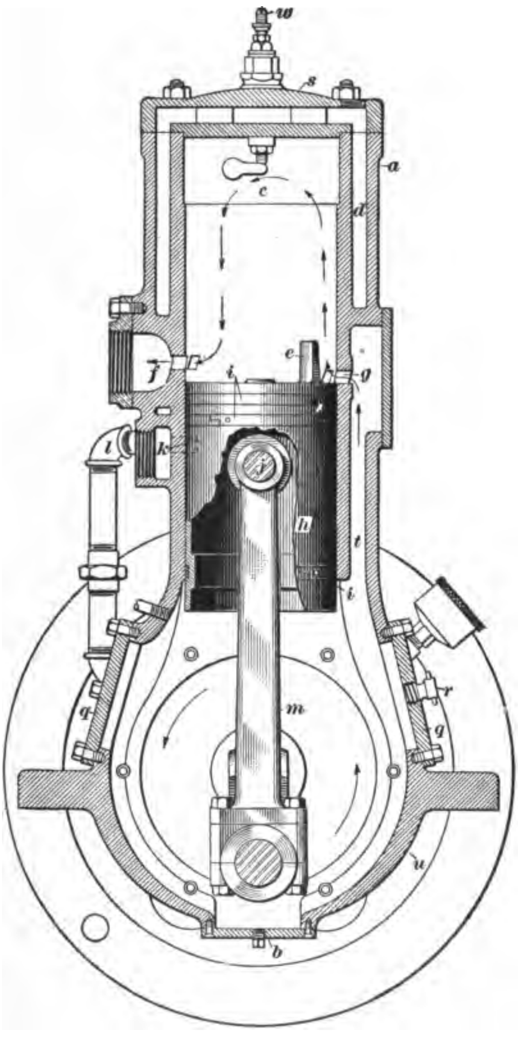


FIG. 33

jacketed head *s* being removable. The combustion chamber *c* of the cylinder is surrounded by a water-jacket *d*. The baffle

plate *e* attached to the piston *h* prevents the incoming gas from passing directly to the exhaust port *f* from the inlet port *g*. The piston *h* and the lower ring *i* are cut away to show the wrist or gudgeon pin *j* and the upper end of the connecting-rod *m*; *k* is the crank-case inlet port, which is opened and controlled by the piston, making a so-called three-port engine. If the inlet were to be placed, say, in the passage *t*, in handhole covers *q*, or elsewhere in the crank-case, the engine would be of two-port construction. The water enters the water-jacket *d* through the pipe *l*, the water being supplied by a pump not shown. A plug to allow oil to be put into the crank-case is shown at *r*. The main bearings for the crank-shaft are not shown, but are in plates that are bolted to the ends of the crank-case casting.

39. The crank-case inlet opening *c* of the two-port engine shown in Fig. 32 corresponds to the port *k* of the three-port engine shown in Fig. 33, with this difference that, on the out-stroke, or the stroke of the piston outwards from the center of the crank-shaft, the explosive mixture in the engine shown in Fig. 32 passes through a check-valve in the supply pipe from the carbureter before entering the crank-case; while in the engine shown in Fig. 33 it enters through the port *k*, which, together with the ports *f* and *g*, is opened and closed by the piston, no check-valve being required to prevent a return of the gas through the intake piping and carbureter, as would happen if the check-valve in Fig. 32 were removed. The check-valve used on the carbureter supply pipe of the two-cycle marine engines may be said to correspond to the inlet valve of the four-cycle type of engine. The inlet valve of the carbureter, or vaporizer, frequently serves as a check-valve, in which case no check-valve need be placed in the supply piping. Some carbureters, however, are so constructed as to make necessary the use of a check-valve to prevent the charge from being expelled from the crank-case. The two-port and three-port types of marine engines are very similar in construction, for it will be observed that by adding a port *k*, Fig. 33, and closing the

pening *c*, the construction shown in Fig. 32 could be emodeled into that shown by Fig. 33; but it would be much asier to convert Fig. 33 into Fig. 32 by closing the port *k* y means of a plug, connecting the supply at any point in ie crank-case or even into the passage from the crank-case o the port *g*, and using a check-valve.

40. Fig. 34 shows a single-cylinder two-cycle marine ngine, in which the lower end of the cylinder, instead of eing open, as in all the ther engines herein described, is closed. The piston rod *a* passes through stuffingbox *b*, connecting rith a crosshead running n suitable guides. The ower part of the cylinder orms the compression pace, serving the same urpose as the crank-case n other two-cycle engines. There is an exhaust port *c*, nlet port *d*, and passover ort *e*, with connection to ne carbureter through the ipe *f*. In *f* is a checkalve to prevent the charge rom passing back into the upply pipe during the rimary compression of ne charge in the lower

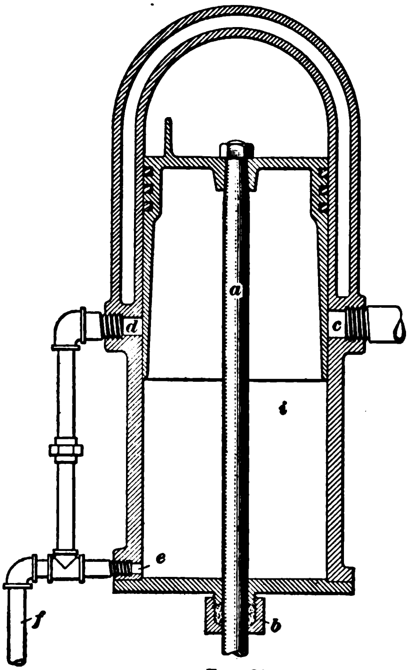


FIG. 34

art of the cylinder. The advantages of this construction re that it is possible to obtain a greater primary compresion than when the crank-case is used as a compression hamber; and the crank-shaft bearings need not be kept tight o prevent loss of primary compression; there is no wear on ne cylinder from sidewise pressure due to the angular posiions of the connecting-rod. Any wear due to this cause

comes on the crosshead and guides, and may readily be take up. Two-cycle horizontal engines are seldom used exce on boats equipped with stern or side paddlewheels, and f such work the engines are usually of the stationary type.

41. Multicylinder Two-Cycle Engines.—The majo ity of two-cycle marine engines are of the single-cylind type; some have two cylinders, a few have three cylinder and occasionally four cylinders are employed, the latte however, but rarely. Double-cylinder two-cycle engine can be built to be almost perfectly balanced, the cran piston, and connecting-rod in one cylinder balancing simil parts in the other. Since the three-port engine has bee brought into use, it has become very much more popul than the double-cylinder two-port engine. The reason f this is that with the three-port engine there is no necessit for two check-valved carbureters, nor for two check-valve (one for each cylinder), such as are required on the suppl pipe from the carbureter with a double-cylinder two-po engine. No check-valves being necessary with a three-po engine, a double connection, or yoke, is sufficient to suppl both cylinders. Moreover, the use of check-valves an separate adjustments for carbureters made the operatio of two-stroke multicylinder engines, to say nothing of star ing, particularly unsatisfactory, because when check-valve were used one cylinder was bound to get a better propo tioned or more explosive mixture than the other. Increasin the number of cylinders gave so much trouble that manufa turers generally discouraged the use of multicylinder two-cycl engines. On the other hand, the double-cylinder three-po engine is very little harder to start than the single-cylinde type, is not much more difficult to keep running, and, o account of its perfect balance, there is little vibration.

Although a larger carbureter is usually employed in th three-port engine, on account of the shorter time allowe for the admission of gas, it will be found good practice t equip three-port as well as two-port multicylinder engine with a separate carbureter for each two cylinders.

FOUR-CYCLE ENGINES

42. Most four-cycle marine engines are of the **multi-ylinder type.** The first double-cylinder marine engines ere made to explode a charge of gas at each revolution. o do this the crankpins had to be in line. With no counter-eights on the crank-shaft to balance the weight of the istons and other re-procating parts, the ibration was excess-ve. Subsequent onstruction, with the anks opposite, gave vo explosions every lternate revolution, nd this is the almost niversal method of onstruction for ouble-cylinder four-ycle engines. An ngine of this sort, hile the reciproca-ng parts are bal-nced, is subject to onsiderable objec-on on account of the ibration set up by the ccelerated motion ue to the second ex-losion, followed by ne idle stroke. The hree-cylinder type of onstruction has been employed with but partial success. The perfectly balanced two-cylinder two-cycle marine engine nd the four-cylinder four-cycle automobile engine, with prac-ically no vibration, created a demand for a vibrationless four-ycle marine engine, and there is now little call for any but our-cylinder engines of from 15 to 75 horsepower. Quite

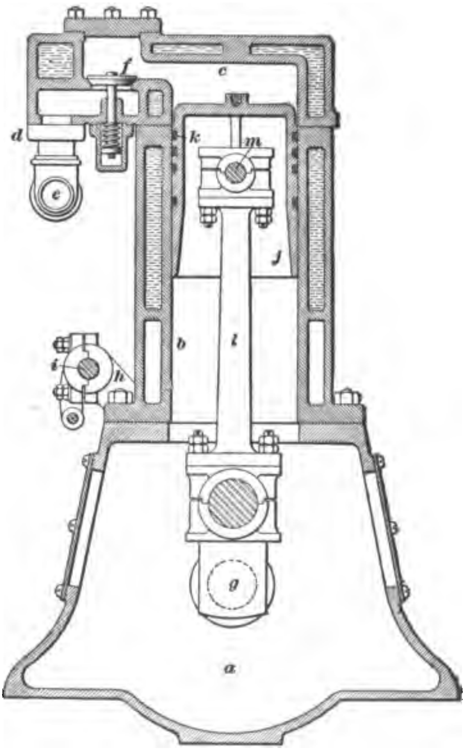


FIG. 35

a number of six- and eight-cylinder marine engines ha
been built in sizes from 100 to 300 horsepower.

As but one of the inlet valves of a four-cylinder engi
of this type is open at a time, the carbureter need be
larger for a four-cycle four-cylinder engine than for a sing
cylinder engine; but a four-cylinder two-cycle two-port engi

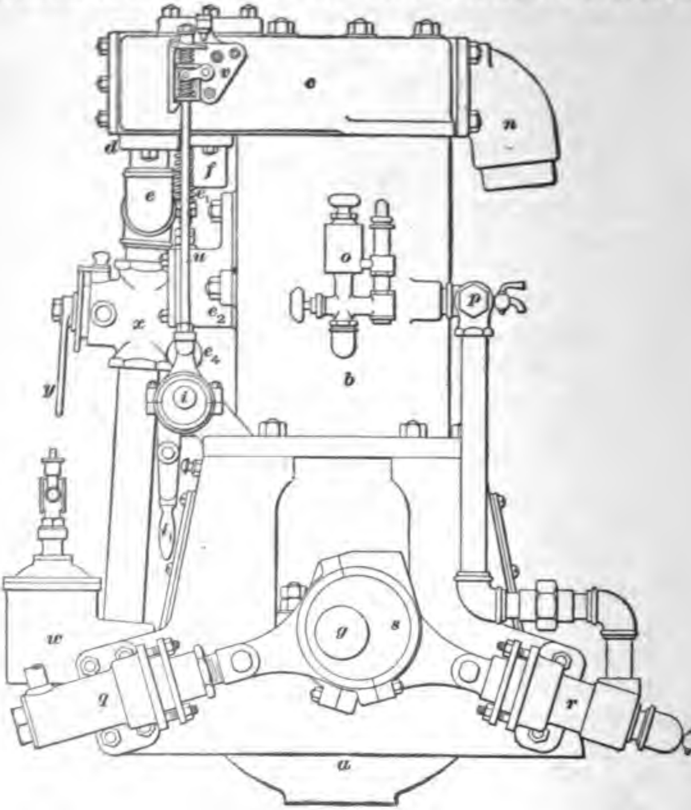


FIG. 36

with cranks set 90° apart, requires a carbureter having tw
the capacity of that for a single- or double-cylinder engin

43. The various types of four-cycle marine engi
differ but little in construction, and for this reason a descr
tion of the parts of the modern four-cycle engine shown

Fig. 35 should be sufficient. With slight changes, this type of engine is made in single-cylinder and multicylinder styles, and in much larger sizes than is the two-stroke type of engine.

Figs. 35, 36, and 37 show the arrangement of the parts in a double-cylinder four-cycle engine, of which Fig. 35 is a

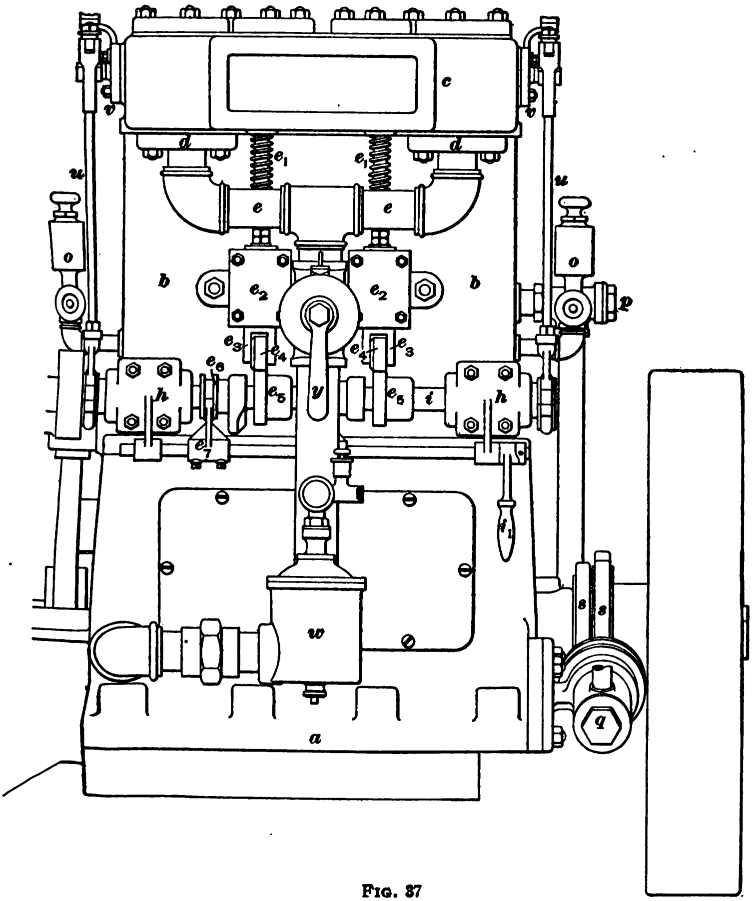


FIG. 37

vertical cross-section. The base or crank-case *a* is surmounted by the jacketed cylinders *b* with the jacketed head *c*. The gas enters through the flange *d* and the inlet pipe *e*.

The inlet valve *f*, which is held to its seat by a spring, controls the entrance of the explosive mixture. In Fig. 35, *g* is the crank-shaft; *h* is the bearing for the cam-shaft *i*, Fig. 37; *j* is the piston, while *k* represents the piston rings; *l* is the connecting-rod; and *m* is the wristpin.

Fig. 36, which is a front elevation with the flywheel removed, shows in addition the exhaust elbow *n*, the lubricator *o*, the check-valve *p* in the water supply, the air pump *q* for operating a whistle, the water pump *r*, the water and air pump eccentric *s*, the drain cock *t*, the igniter rod *u*, the igniter bonnet *v*, the vaporizer *w*, the throttle valve *x*, and the throttle lever *y*.

Fig. 37, which is a side elevation, shows the exhaust-valve mechanism, including the exhaust-valve springs e_1, the valve-stem guide and cap e_2, the valve lifter e_3, the roller e_4, the exhaust-valve cam e_5, the cam-shifting collar and relief cam e_6, the shifting fork e_7, the cam-shaft *i*, the cam-shifting lever i_1, and the flywheel.

44. The six-cylinder marine engine shown in Fig. 38 is of what is known as the *open crank-case type*. Longitudinal rigidity in this engine is obtained by using a base consisting of two **Z** bars *a, a*, to which are bolted the manganese bronze struts, or frames, *b, b* that support the cylinders *c* and tie them together.

The inlet valves *d* and the exhaust valves (not shown) on the opposite side are set at an angle of 45° to the vertical cylinder walls. They are mechanically operated by means of rocker-arms *e, e* actuated by a cam-shaft (not shown) above the top of the cylinders. The cam-shaft is driven by the crank-shaft through bevel gears in the cases *f* and *g*, and is enclosed so as to run in oil, the cams thus being kept free from grit and dirt. The valves, valve seats, and springs are self-contained in cages that may readily be removed from the cylinder head by unscrewing the locking rings that hold them in place and withdrawing the corresponding rocker-arms *e* by which the valves are operated. By removing the valves, the cylinder and combustion-chamber

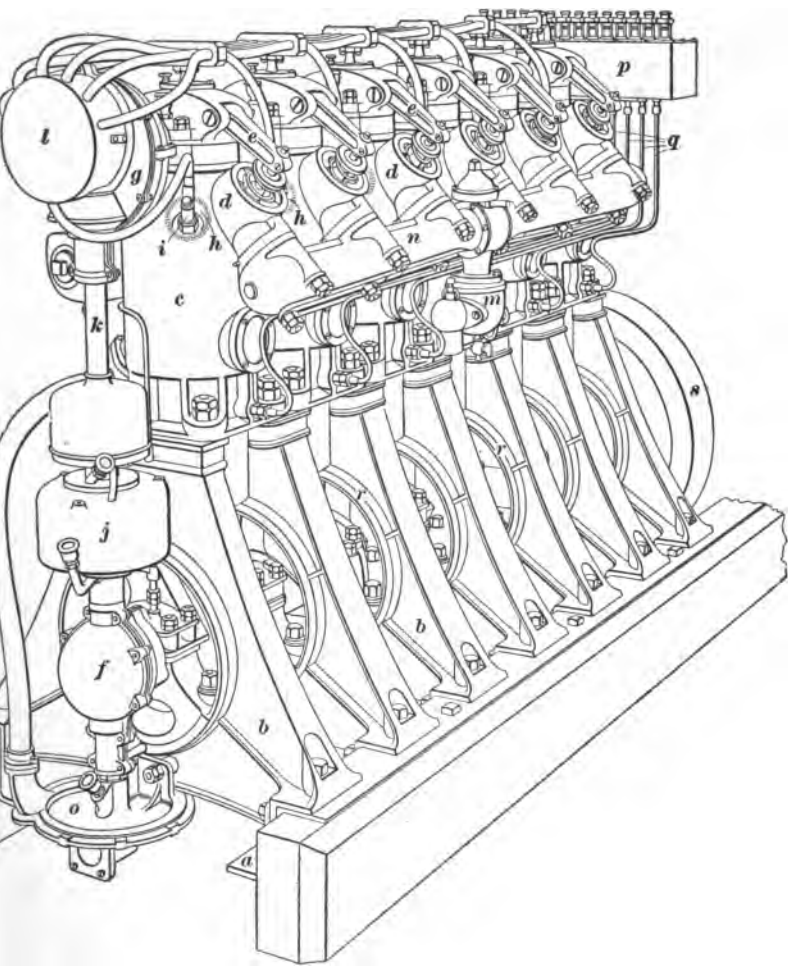


FIG. 38

walls may be readily and fully inspected and any carbon deposit due to improper lubrication removed.

Two depressions *h*, one on each side of each inlet valve, are provided to receive the spark plug *i* and the priming cup, respectively. In each of the depressed openings is a hole leading into the cylinder and having a standard spark-plug thread, so that the spark plug may be placed on either side of the inlet valve, the combined priming and relief cock being placed in the opposite hole.

45. Current for a high-tension ignition system is supplied by an inductor type of alternating-current generator *j* mounted just above the bevel-gear casing *f* on the vertical shaft *k* that drives the cam-shaft. The rotor, or rotating element, of the alternator is pinned to the vertical shaft and does not have any wire winding or commutator segments. The alternator casing is provided with an arm or projection at the end of which there is a link connection to the carbureter, so that, when the proportions of the combustible mixture are changed in order to vary the engine speed, there is a simultaneous and corresponding change in the time of sparking. The distributor *l*, geared to, and rotating at the same speed as, the cam-shaft, is mounted on the upper bevel-gear casing *g*, this arrangement permitting the use of short neatly arranged lengths of wire to the spark plugs.

The combustible mixture passes from the carbureter *m* into a manifold *n* and thence into the cylinders. A uniform quality of mixture under varying degrees of throttling is insured by maintaining the same relative effective areas of the throttle valve and air-inlet openings.

46. A centrifugal water-circulating pump *o* is attached to the lower end of the vertical shaft *k* by which the cam-shaft is driven. The pump is placed below the water-line, and hence does not require priming. It forces a large quantity of water into a manifold on the exhaust side of the engine near the bottom of the cylinder water-jackets, whose volume is greater at the top than at the bottom. Enlargement of the water space toward the top of the water-jacket

provides for an increased volume of water around the exhaust valves. Water enters the bottom of the jacket on the exhaust side and leaves it on the same side at the top above the exhaust valves, the seats of which are thus kept cool. From the top of the water-jackets the water passes into a jacket around the exhaust manifold, thence into the exhaust pipe at a point from 12 to 18 inches away from the manifold.

47. At the end of the cam-shaft opposite the distributor is placed a multiple, sight-feed, mechanical lubricator *p* from which a number of small copper pipes *q* distribute oil to the cylinders and main bearings. Part of the oil fed to the cylinders works its way through the hollow piston pins into a hole drilled through the center of each connecting-rod and thence to the crankpins. The latter are also lubricated through the action of centrifugal force, which causes a flow of oil from grooved oil rings mounted on and concentric with the crank-shaft. The oil rings are supplied by the overflow of oil from the crank-shaft bearings. For the latter and for the crankpins, interchangeable Babbitt-metal bushings are used.

To prevent throwing of oil, the crank-shaft is enclosed with narrow, flexible, and readily adjustable strips of sheet steel, backed on the bearing edges with felt, forming a connection between the circular flange *r* on one strut and that on the neighboring strut. A hole in the bottom of each of these strips permits any excess of oil to flow into an inclined pipe below them, thence passing into a vessel from which the oil is drawn through a strainer by a pump and again used.

48. The flywheel *s* is placed at the aft end of the engine, and is attached to a flange that forms part of the crank-shaft. The reverse mechanism and thrust bearing are mounted on the **Z** bars *a*, *a* of the base, thus making with the engine a single unit all ready for coupling to the propeller shaft.

49. Speed Flexibility and Piston-Speed Limits. Speed flexibility is a term used to denote the range of speeds that an engine is capable of making. The four-cycle

engine can be run at a higher speed than the two-cycle engine without excessive heating of the cylinders. The amount of compression and the size and weight of the flywheel regulate the minimum speed. The flywheels of four-cycle engines, because power is developed in each cylinder during but one stroke in four, are usually heavier than those of two-cycle engines, while the four-cycle engine ordinarily uses a higher compression.

When a gas engine can be run with its compression relieved and at the same time exploding a smaller volume of charge, it may be run at a much slower speed than would otherwise be possible. As nearly all marine four-cycle engines are provided with a compression-relieving device, they have a decided advantage over two-cycle engines, which cannot so readily be thus equipped. The relief of compression in four-cycle engines is usually accomplished by means of single- and double-lipped cams that operate the valve lifters, or push rods.

LIFE OF MARINE GAS ENGINES

50. The slow-speed engine has a considerably longer life than medium- or high-speed engines, as increasing the speed increases the wear. Four-cycle engines are said to have a longer life than two-cycle engines, but their length of life depends largely on conditions of use, design, care, etc.

A heavy slow-speed engine is better adapted for use in a heavy boat, while with an extremely light construction of hull a light high-speed engine could be used with propriety. Lightly constructed boats, however, are very short lived. Medium-weight engines are naturally better adapted to craft that are neither abnormally heavy nor extremely light. An engine will give the best results when it is adapted to the requirements to be met; it is better to have an engine a little too heavy than one that is too light.

STATIONARY GAS ENGINES
(PART 1)

HORIZONTAL FOUR-CYCLE TYPES

CONSTRUCTIVE FEATURES

1. Series of Operations.—In gas engines of the four-stroke cycle, or, briefly, the four-cycle, type, the gas is drawn into the cylinder on the first, or outward, stroke; compressed and ignited on the second; burned and expanded during the third; and the products of combustion are driven from the cylinder, or exhausted, during the fourth stroke. This series, or cycle, of operations is repeated for each working, or power, stroke of the engine, the third stroke being the only working stroke. Most horizontal engines of this class are of the single-cylinder type and are single-acting, having long-trunked pistons to which the connecting-rods are directly attached, the piston taking the place of the crosshead and piston rod that are necessary with engines of the double-acting type.

2. Classification.—Stationary gas engines of the four-cycle type may be classified according to the means by which their operation under varying loads is regulated or governed. By what is known as the **hit-or-miss method** of governing, speed regulation is effected by the governor in closing the inlet valve when the speed of the engine exceeds the limit for which the governor is set, thus causing explosions to be missed until the engine regains its normal speed,

whereupon charges of gas are again admitted and exploded in regular order.

With the **throttling method** of governing, the governor operates a throttle valve in the inlet pipe, closing it as the load decreases and the speed increases, and opening it as the load increases and the speed decreases. The charge is either decreased by throttling the inlet or else it is made weaker by throttling the fuel supply. Both methods serve to reduce the power generated by the explosion, thus causing the engine speed to fall to its normal rate.

3. According to the methods of governing employed, four-cycle engines may be classified as follows:

1. Engines that are governed by varying the number of charges according to the work performed by the engine, the governor controlling the fuel valve only and working on the hit-or-miss system, under which the engine misses one or more cycles when its speed rises above the normal. When illuminating gas is used, regulation is accomplished simply by allowing the gas valve to remain shut while the inlet and exhaust valves continue to act. This results in pure air instead of an explosive mixture being taken into the cylinder, the air being compressed, reexpanded to its original volume, and discharged on the exhaust stroke.

2. Engines that are governed by the hit-or-miss system, in which the governor controls the exhaust valve directly, and the fuel valve indirectly. Such engines have suction-lifted inlet valves, and the exhaust valve is usually held open during the idle cycle or cycles, so that the burned gases in the exhaust pipe are merely pumped in and out of the cylinder without affecting the inlet valve. Sometimes, the connection between the valve and the cam that operates the valve is interrupted, so that the latter stays shut and the burned gas in the cylinder is compressed and reexpanded until the exhaust valve opens again.

Under the hit-or-miss system of governing, a full charge is taken into the cylinder whenever any charge at all is used, and consequently the full normal compression is always used.

Hence, the hit-or-miss system is more economical of fuel than the throttling system of governing, in which the mixture stream is throttled for light loads. The hit-or-miss system has the objection, however, that it makes the engine run somewhat fitfully in spite of even a heavy flywheel. Therefore, this system is not adapted to engines for electric lighting and similar service, and is most frequently employed with single-cylinder engines, in which economy of fuel is the prime object. There is, however, no special mechanical difficulty encountered in applying this system to engines of any number of cylinders. When this is done, the governor first cuts out one cylinder, then the next, and then another, by slight gradations of speed. This prevents the power from being shut off too abruptly.

3. Engines in which the governor controls both the air and the fuel inlet or mixing valve, throttling the charges under light loads, but admitting some gas mixture at every stroke. The throttling system of governing is less economical than the hit-or-miss method, but it has the advantage of giving smoothness and quietness of running and continuity of impulses.

A modification of the throttling system is to have the governor act on a sliding wedge that restricts the opening of the inlet valve. With this or the preceding arrangement, the inlet valve may be opened either automatically or mechanically.

Another modification of the throttling system is to throttle both the gas and the air simultaneously. This is not often done, but it may be accomplished by passing the gas and the air through separate ports controlled by a single suction-lifted valve. This valve is acted on by the governor to restrict its lift, and the inlet valve is opened mechanically to reduce the suction needed.

Another system of engine control, which may or may not be operated automatically by a governor, is to restrict the opening of the exhaust valve. This is accomplished by a movable connection between the valve and the exhaust cam, which acts both to restrict the lift of the valve and to close it earlier in the exhaust stroke, so that a portion of the burned

gases are retained. The effect of this is to prevent the inlet valve (which here is always automatic) from opening until the piston has completed a greater or less portion of the suction stroke. Consequently, at the end of the suction stroke, the piston has a considerable body of burned gas next to it, and the fresh mixture fills the combustion chamber, where it is close to the igniter and easily fired.

An engine of any of the foregoing three classes may be equipped with a single poppet valve, through which all the exhaust gases are expelled during the exhaust stroke; or, in the wall of the cylinder, it may have what is known as an auxiliary exhaust port, which is uncovered by the piston at the end of the expansion stroke and through which the larger portion of the burned gases escape, while the remainder is expelled through a smaller poppet valve during the exhaust stroke of the piston.

ENGINES WITH HIT-OR-MISS CONTROL OF THE FUEL VALVE

GASOLINE ENGINE WITH VERTICAL FLYBALL GOVERNOR

4. General Appearance of Engine.—In Fig. 1 is shown the general appearance of a medium-sized gasoline engine of about 15 horsepower. The height of the bed is such that it is necessary to raise the engine above the floor level by means of a brick or concrete foundation, in order that the flywheels may clear the floor. The valves, governor, and igniter are operated from a cam, ór secondary, shaft, shown at *a*, running alongside of the engine, supported by bearings, shown at *b* and *c*. The cam-shaft is driven from the crank-shaft by a pair of spiral gears, shown at *d*, *d*, at one-half the speed of the crank-shaft. The gasoline is pumped from the supply tank by a small pump, shown at *e*, to the cup *f*, from which it flows by gravity to the gasoline inlet valve, the overflow from the cup returning to the supply reservoir. The gasoline pump is driven from an eccentric on the cam-shaft *a*. The governor *g* is of the

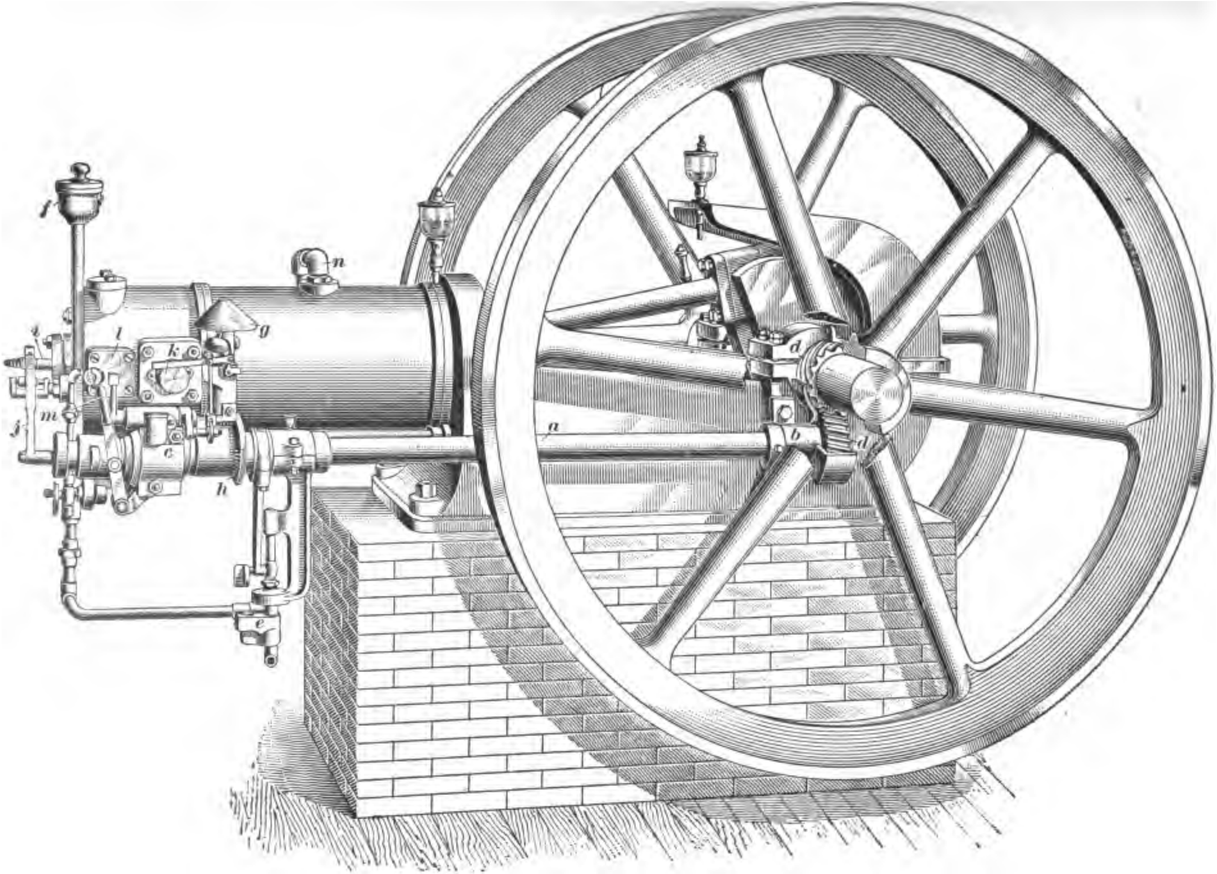


FIG. 1

centrifugal type, in which the regulation is effected by the centrifugal force of rotating balls, known as *flyballs*. The governor is driven from the cam-shaft by the bevel gears shown at *h*. The charge is ignited by an electric igniter *i*, operated from the cam-shaft by the link *j*.

The inlet valve to the cylinder is inside the casing *k* and the gasoline admission valve in the casing *l*. The hand lever *m* is for the purpose of shifting the cam by which the exhaust valve is opened so as to relieve compression in the cylinder when the engine is being started. The cooling water that circulates through the water-jacket is discharged through the pipe *n*.

5. Inlet Valves for Fuel and Air.—The inlet valves for gasoline and air are shown more clearly in the sectional plan, Fig. 2. The gasoline valve body *a* contains the gasoline poppet valve *b* and the gasoline needle valve *c*. A small quantity of gasoline is maintained in the cup *f*, Fig. 1, by the action of the gasoline pump *e*. The gasoline supply can be turned on or shut off by means of a cock between the pump and the cup. The cup is elevated so as to create a slight pressure of gasoline in the passages of the gasoline valve. The gasoline enters the gasoline poppet valve *b*, Fig. 2, through the hole *d* and the needle valve *c*, the opening through which is adjusted by screwing the valve in or out by hand. The valve *b* is opened by a cam acting on a bell-crank lever that engages a slotted nut on the end of the valve.

6. The air is taken from a space under the engine bed and is conveyed to the cylinder head by a pipe attached to the bottom of the head. From there, it passes upwards until it reaches the port shown at *e*, Fig. 2. During the first, or suction, stroke of the piston *f*, a partial vacuum is created in the combustion chamber *g*, which causes the inlet valve *h* to be drawn open against the action of the light coil spring *i*. This causes the air in the air pipe to rush with considerable velocity through the ports *e* and *j*. At the same time, the gasoline valve *b* is opened by the cam-motion, and gasoline under pressure from the gasoline cup

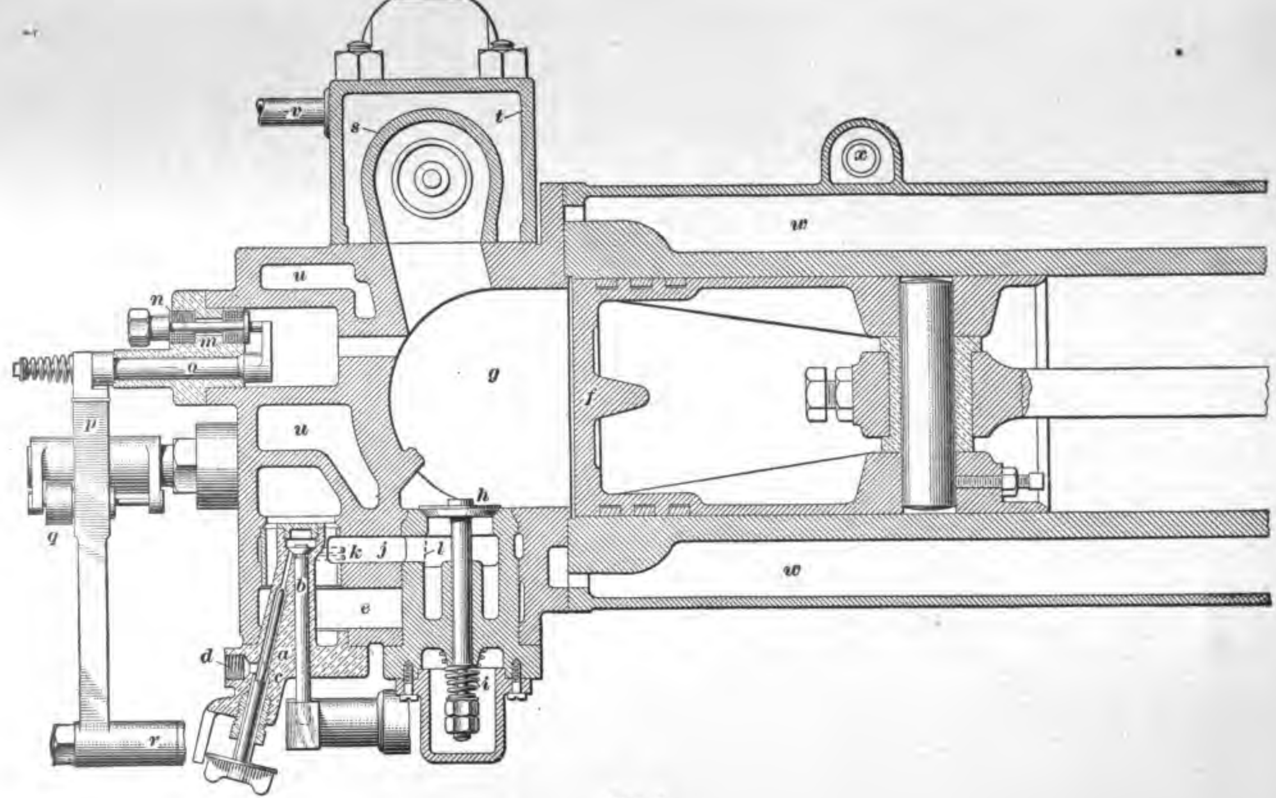


FIG. 2

is sprayed into the air-current through a small hole in the nozzle, shown dotted at *k*. The gasoline is vaporized while passing into the combustion chamber through the open valve *h*. To facilitate the vaporization of the fuel, a wire-gauze screen *l* is fastened to the inner wall of the inlet-valve casing.

The charge of air and gasoline vapor thus formed is drawn into the cylinder during the entire suction stroke of the piston. On the following, or compression, stroke, the pressure closes the inlet valve *h* and the mixture is compressed until the piston reaches the position shown in Fig. 2. Just before it reaches this point, the action of the igniter, shown at *m*, produces a spark in the combustion chamber and fires the compressed mixture.

The igniter consists of the stationary electrode *n* and the movable electrode *o*, both being fitted with platinum contact points. It is operated by the lever *p*, which moves back and forth on the fulcrum *q*, and is driven by the pin *r* set eccentrically on the end of the rotating cam-shaft.

7. Water-Jackets.—Fig. 2 also shows the exhaust-valve casing *s* surrounded by a water-jacket *t*. The exhaust valve is vertical, so that only the top of it is shown by the circles within the casing. The igniter is also surrounded by a water-jacket, shown at *u*, in the cylinder head. Water enters the jacket around the exhaust valve by the pipe shown at *v*, passes through the jacket *u* in the cylinder head, and then to the jacket *w* around the cylinder. The water finally leaves the jacket at the top of the cylinder through a pipe that delivers it to the funnel *x* on the side of the water-jacket, from which it is conducted to the sewer or waste pipe.

8. Exhaust Valve, Lever, and Cam.—Fig. 3 (*a*) shows an end view of the cylinder head, with the exhaust-valve casing in vertical cross-section, while Fig. 3 (*b*) is a side view of the head, showing the location of the inlet valves and the igniter. Referring to Fig. 3 (*a*), the exhaust-valve casing *a* is bolted to the side of the cylinder head *b* and contains the vertical poppet valve *c*. This valve is opened

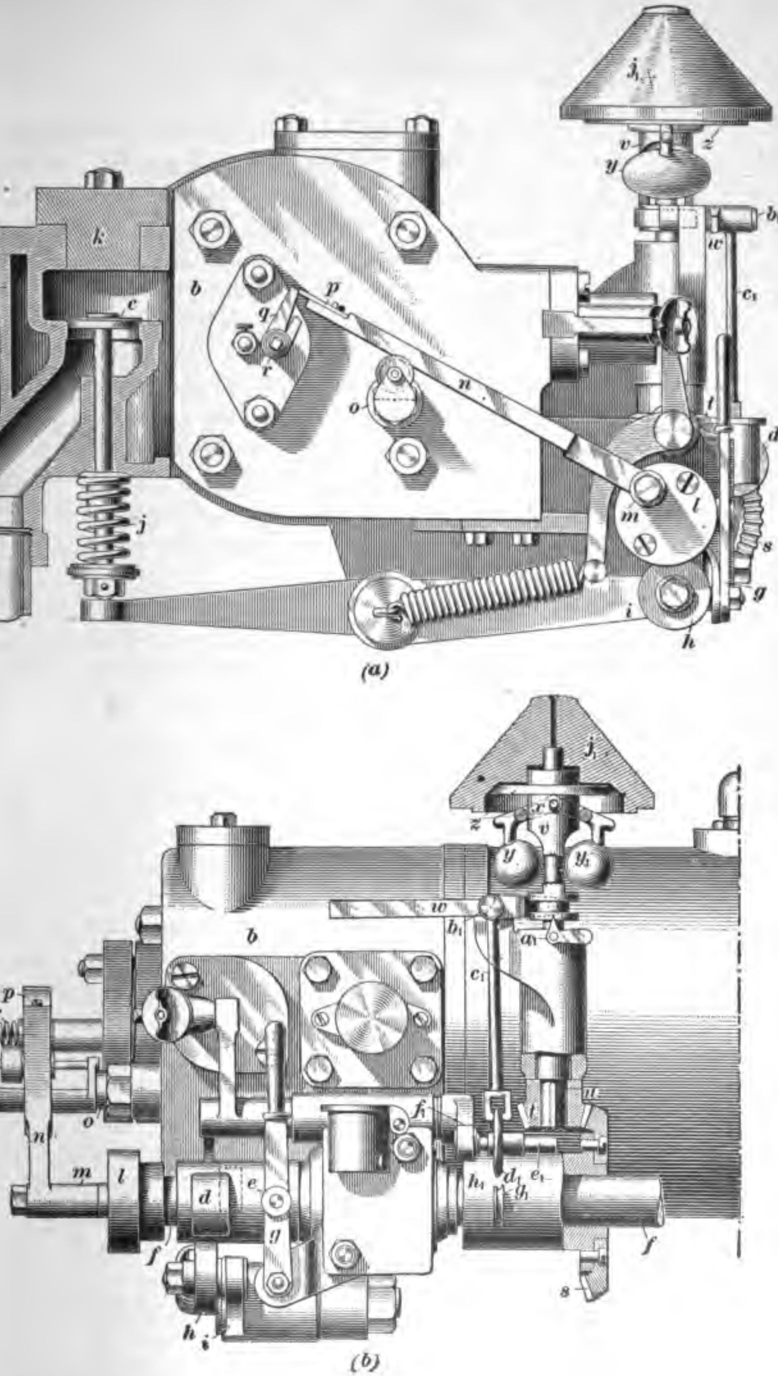


Fig. 3

by the cam, shown at *d*, Fig. 3 (*b*), mounted on the sleeve *e*, which is fitted on a feather key in the cam-shaft *f*. A hand lever *g* is used to slide the sleeve *e* on the cam-shaft, so that a small auxiliary exhaust cam, located on the same sleeve with the main cam, can be brought opposite the roller *h* on the end of the rocker-arm shown at *i*, Fig. 3 (*a*). When the cam-shaft rotates, either of these cams can be made to force the roller *h* downwards and thus open the exhaust valve *c*. However, the small cam is used only in starting the engine. It lifts the exhaust valve partly from its seat during the early part of the compression stroke, thus allowing the pressure in the cylinder to be relieved by permitting some of the compressed gas to escape through the exhaust pipe. This makes it possible to turn the engine by hand while starting.

The exhaust valve *c*, Fig. 3 (*a*), is drawn to its seat by the spiral spring *j*, which is held in place by a washer and locknut as shown. The removable cover *k* permits the valve to be removed for the purpose of cleaning or grinding the valve seat.

9. Igniter Lever and Cam.—On the end of the cam-shaft is mounted a disk *l* with a pin *m* located a short distance from the center of the disk so as to give a reciprocating motion to the igniter rod *n* connected to the pin. As the rod is supported by a roller on the stud *o* screwed into the cylinder head at a suitable distance from the eccentric pin *m*, it is thereby made to describe an elliptic motion at the end to which the steel blade *p* is attached. The roller on the stud *o* has two steps, on either one of which the rod *n* may rest as it rocks back and forth. When the rod rests on the larger portion of the roller, the blade *p* is raised into a position where the electrodes of the igniter will separate at the proper time, and thus produce the spark in time for firing the compressed charge when the crank is near the inner dead center. When starting the engine by turning the flywheels by hand, the point of ignition should be retarded so as to produce the spark somewhat later—that is, after the crank

has passed the inner dead center to avoid any sudden backward turning of the wheels and possible injury to the operator. In order to accomplish this, the point of the blade *p* is lowered by shifting the roller on the stud *o*, so that the rod rests on the small part of the roller.

In Fig. 3 (*a*), the eccentric pin *m* is shown in such a position that the igniter rod *n* has almost reached its extreme travel to the left, causing the two electrodes to be brought in contact, and the interrupter lever *q* is about to be released by the blade *p*. As soon as this occurs, the spring shown at *r*, Fig. 3 (*b*), being under tension, causes the two electrodes to be separated quickly. The initial tension of the spring is increased, owing to the fact that the lever *n* continues to move farther to the left after the electrodes have been brought into contact. This not only gives more power to the spring, but also makes a firm contact that lasts sufficiently long to insure a flow of current from one electrode to the other, and consequently a spark when they separate.

10. The Governing Mechanism.—The governing mechanism is also illustrated in Fig.. 3 (*a*) and (*b*). The governor is of the centrifugal, or flyball, type, and is driven by the large bevel gear *s*, Fig. 3 (*b*), on the cam-shaft *f*, meshing with the smaller pinion *t*, keyed to the governor spindle *u*. This spindle revolves in a vertical bracket bolted to the cylinder. On the upper end of the spindle is fitted a sleeve *v*, the lower end of which is grooved to receive a fork attached to the governor lever *w*; while the upper end has a slot through which a pivot pin *x* passes. The sleeve at this point is flattened at both sides, and the two flyballs y, y_1 are loosely fitted with their fork-shaped arms over the flat portion of the sleeve. The pivot pin *x* fits tightly in the governor spindle, but loosely in the sleeve *v*, and the oval slot in the sleeve allows the latter to be moved vertically when the balls, moving outwards by their centrifugal force, come in contact with the disk *z* of the sleeve. Fig. 3 (*b*) shows the position of the flyballs when the governor sleeve is propped up and the engine is standing still

ready to be started. It will be seen that the governor bracket carries at its upper end a small stop-lever a_1, the horizontal arm of which is sufficiently heavy to cause it to turn on its pin when released from the weight of the governor sleeve. The bell-crank lever w is pivoted at b_1, and its vertical arm c_1 is forked at the lower end. In the fork is a roller d_1 that is free to rotate on the pin e_1. This pin is riveted into the short arm of the bell-crank lever f_1 that opens and closes the gasoline valve. There is a cam g_1 on the sleeve h_1 that rotates with the cam-shaft, and each time the roller d_1 strikes this cam the pin e_1 is raised, thus turning the bell-crank lever f_1 and opening the gasoline valve.

11. When starting, the governor sleeve v is raised and propped up by the stop-lever a_1. This motion of the sleeve is transmitted to the arm c_1, and the roller d_1 is shifted horizontally on the pin e_1 and is held by the fork in such a position that it is directly opposite the cam g_1. At every revolution of the cam-shaft, therefore, the gasoline valve is opened. As the speed of the engine increases and approaches the normal, the balls of the governor move outwards and upwards, swinging on the pin x. As they move upwards, their arms come in contact with the disk z attached to the sleeve v, and raise the sleeve enough to free the lever a_1. The heavy end of this lever at once falls into a vertical position, thus turning the short arm into a horizontal position. If the engine is now allowed to stop, the sleeve v descends until it rests against the bracket. This motion depresses the short horizontal arm of the lever w and causes the arm c_1 to move to the left. The fork at the lower end of the arm c_1 then shifts the roller d_1 to the left on the pin e_1, with the result that the cam g_1 no longer strikes the roller and the gasoline valve is not opened. Thus, it is impossible for the engine to stop with the gasoline valve open.

On the other hand, when the load on the engine is light and the speed rises above the normal, the governor balls lift the sleeve v so that the lever c_1 shifts the roller d_1 in the opposite direction and allows the cam g_1 to pass by the roller

on the right side. The gasoline valve will then remain closed, and no fuel will be admitted until the speed decreases sufficiently to cause the governor balls to descend and again bring the roller opposite the cam. The cap, or weight, *j*, of the governor, which rests on top of the sleeve *v*, is so proportioned as to give the engine the desired speed. A heavier weight would exert more pressure on the sleeve, and it would require a higher speed and more centrifugal force of the flyballs to move the roller out of reach of the gasoline cam; while a lighter weight would have the opposite effect, and cause the engine to run at a decreased speed. When propped up for starting, as explained above and as shown in Fig. 3 (*b*), the flyballs are in contact with the sleeve, but the sleeve is not affected by the weight, the latter exerting its influence only when the speed begins to approach the normal. The longer horizontal arm of the governor lever *w* serves to receive a counterweight, by means of which the speed of the engine can be temporarily decreased if desired. The shifting of the weight on this arm of the lever permits the speed to be varied while the engine is running.

GAS ENGINE WITH VERTICAL FLYBALL GOVERNOR

12. The difference between the design of the gasoline engine just described and that of a gas engine of the same size and type is illustrated in the side view of the cylinder head, Fig. 4, and in the horizontal sectional view of the cylinder and combustion chamber, Fig. 5. The only difference consists in replacing the gasoline pump, overflow cup, and connections required for handling the liquid fuel, by differently designed valves for admitting the charge to the cylinder. The exhaust, ignition, and governing mechanisms are exactly the same as those of the gasoline engine, and there is no difference in the engine bed, crank-shaft, connecting-rod, piston, cylinder, cylinder head, and jacket.

13. The gasoline cock is replaced by the gas-cock, or throttle, shown at *a*, Fig. 4, and consists of an iron body and brass taper plug to which is fastened a hand lever *b*. A

graduated dial, which is fastened with screws to the body of the cock, is placed between the hand lever and the cock, enabling the operator to open the latter to any desired extent. The gas port *a*, Fig. 5, extends vertically in the cylinder head, registering with a corresponding port in the bottom of the gas-cock. The gas-admission valve consists of a casing *b*, inserted in and bolted to the cylinder head, and containing a steel poppet valve *c*. The valve is opened by a bell-crank lever, shown at *c*, Fig. 4, when the governor

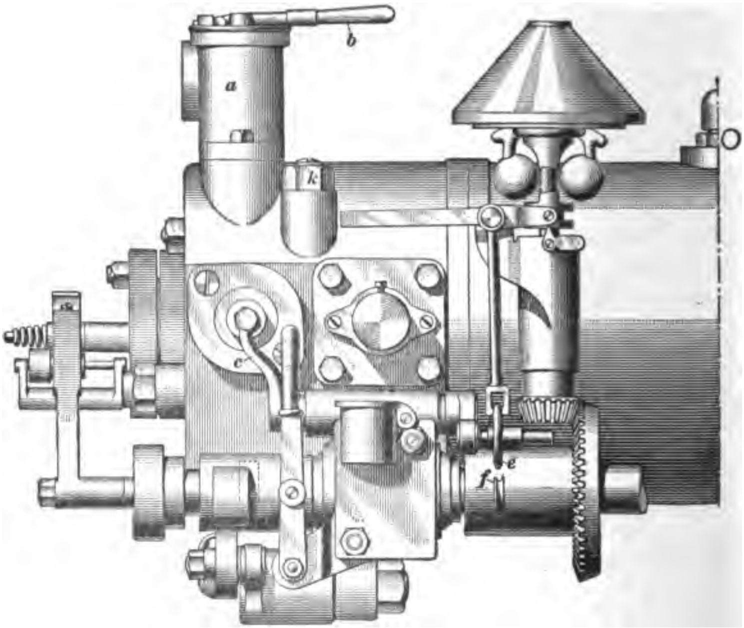


FIG. 4

lever brings the roller *e* and cam *f* together, as in the gasoline engine. The poppet valve *c*, Fig. 5, opens against the gas pressure, and is closed by the spiral spring *d*. When the valve is open, the gas passes through it and enters the space *e*, which surrounds the body *f* of the air inlet and mixing valve. From there, the gas enters the mixing valve through a number of small holes *g* drilled into the body of the mixing valve, where it mingles with the air

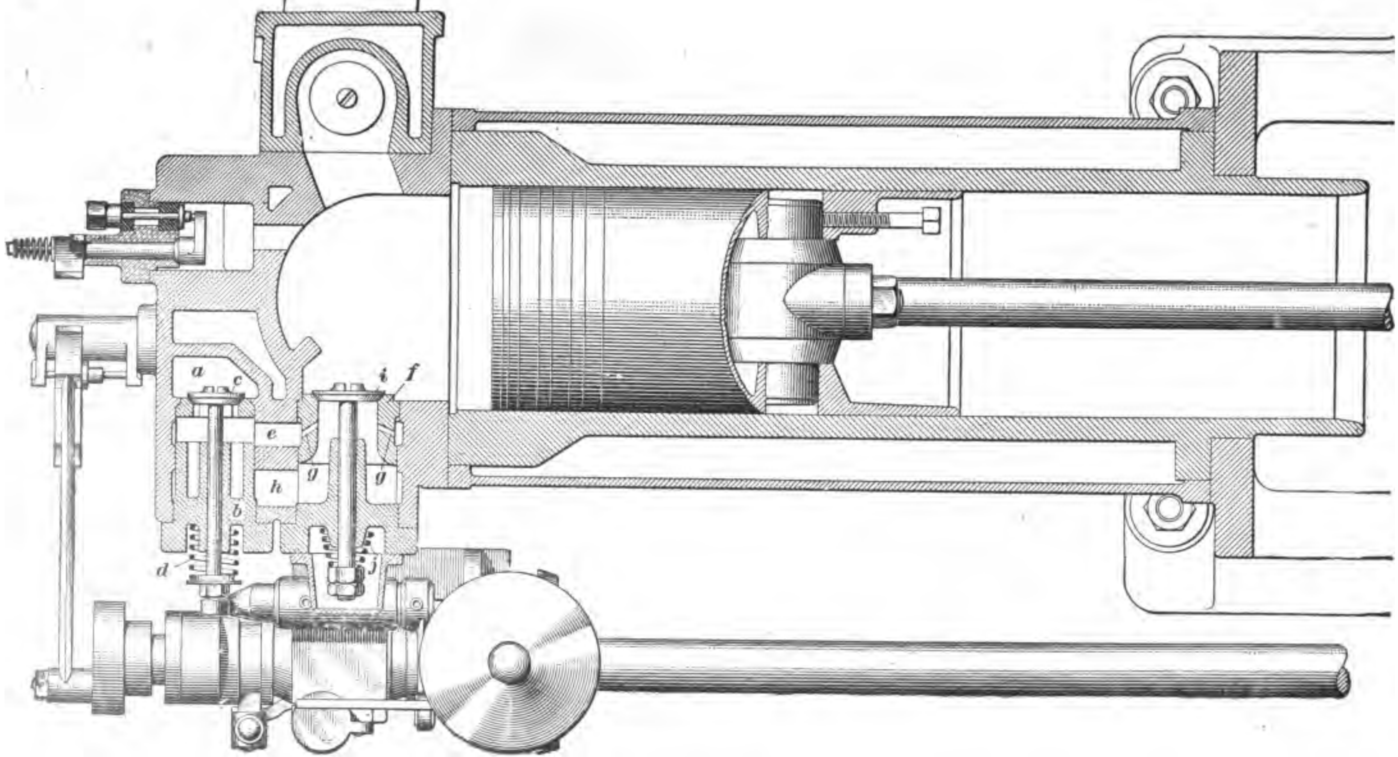


FIG. 5

entering through the port *h*, which extends downwards in the cylinder head until it connects with the air-supply pipe leading from the head to the space underneath the engine bed.

14. The inlet poppet valve *i* opens automatically against the comparatively weak spiral spring *j*, as soon as the forward movement of the piston creates a partial vacuum in the cylinder during the suction, or aspiration, stroke. A regulating screw, shown at *k*, Fig. 4, serves to obstruct the flow of the gas in the port *e*, Fig. 5. The screw is raised or lowered until the quantity of gas admitted to the engine, with the throttle cock *a* wide open, is such as to give a proper mixture of gas and air and consequently a maximum amount of power developed by the engine. In this manner, it is possible to vary the amount of gas admitted to conform to the quality and the pressure prevailing in different localities. After the charge of gas and air has been admitted as just described, the cycle of operations that follows is the same as in the gasoline engine already described.

GAS ENGINE WITH HORIZONTAL FLYBALL GOVERNOR

15. Cylinder and Valves.—The details of another type of engine governed by controlling the full valve, but with differently designed valve mechanism, electric igniter, and governing device, will now be considered. Fig. 6 is a sectional view of the combustion chamber, showing the cylinder, inlet-valve, and exhaust-valve casings, and the rocker-arms that operate the valves. The valve casings are attached to opposite sides of the cylinder *a*, the inlet valve *d* being on the right-hand and the exhaust valve *e* on the left-hand side. The inlet valve is cooled by the incoming charge, while the exhaust valve is surrounded by a water-jacket *c* communicating with the cooling-water space of the cylinder. The inlet valve *d* and the exhaust valve *e* are provided with cast-iron heads, into which steel stems are screwed and riveted. Both valves are opened by rocker-arms, shown at *f* and *g*, connected to the inlet and exhaust roller levers by horizontal rods passing through the inside of the engine

bed. Coil springs, shown at *i* and *j*, force the valves on their seats when released by the cams.

16. The rocker-arm shaft *k* is supported by the two bearings attached to the lower part of the engine bed. In order to be able to operate the two rocker-arms independently of each other, the arm *f* opening the inlet valve turns loosely

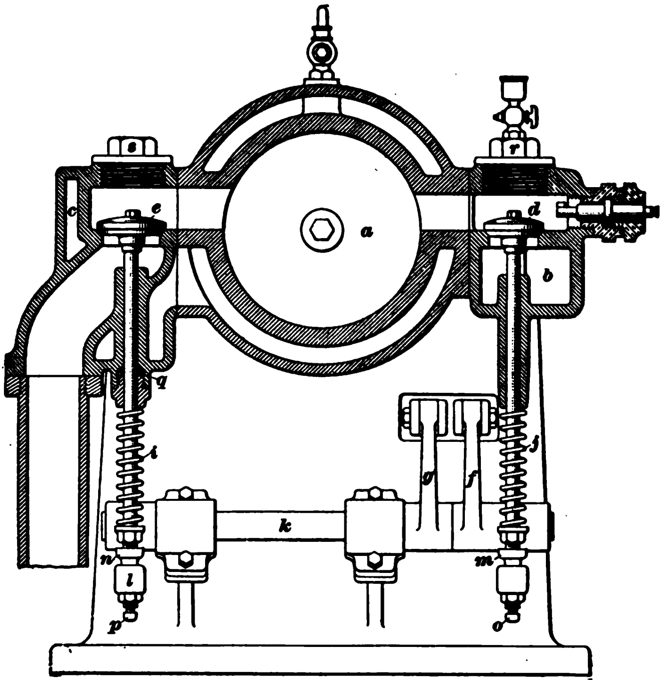


FIG. 6

on the shaft *k*, while the arms *g* and *l* are attached rigidly to the shaft and when operated cause the shaft to oscillate in its bearings. Small cups *m* and *n*, attached to the upper ends of the setscrews *o* and *p*, are kept filled with lubricating oil to reduce the wear on the ends of the valve stems. The exhaust valve *e* is fitted with a stuffingbox *q* containing a quantity of graphite that assists in lubricating the valve stem and prevents it from sticking in the guide. Both

inlet and exhaust valves can be removed for cleaning or grinding after unscrewing the caps *r* and *s*.

17. Cams and Levers.—Fig. 7 illustrates the gears, the cam-shaft and cams operating the exhaust, the air-inlet and gas-admission valves, and the eccentric and rod that actuate the igniter. The cam-shaft *a* revolves at one-half

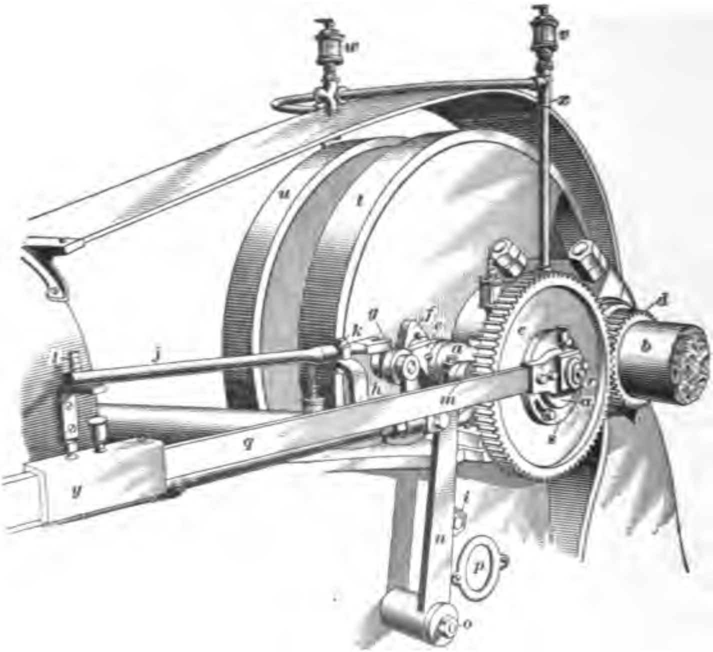


FIG. 7

the speed of the crank-shaft *b* through the medium of the 2-to-1 spur gears *c* and *d*. The inlet-valve cam *e* and the exhaust-valve cam *f* are mounted on the cam-shaft *a* and held in position by setscrews, the ends of which fit into countersinks in the cam-shaft. While revolving, the cams push against the rollers *g* and *h* attached to the upper ends of levers pivoted at *i*, the lower ends of the levers being connected to horizontal rods that transmit motion from the cam-shaft to the rocker-arms *f* and *g*, Fig. 6. A small

auxiliary cam, not shown in the illustration, but located opposite the exhaust cam, serves to permit part of the compression pressure in the cylinder to escape, in order to facilitate the turning of the engine by hand while starting. The auxiliary cam is set so that the exhaust roller *h*, Fig. 7, is not engaged by it unless the roller is shifted over toward the crank-disk *t* by means of the forked shifting lever *j* pivoted at *k*. After the engine has received a few impulses and begins to attain its speed, the roller *h* is shifted back so as to engage the main exhaust cam only, being held in this position by the dowel-pin *l* in the end of the handle of the shifting lever.

18. The cam that operates the gas valve is attached to the inside of the large gear *c* and pushes against the roller *m* on the end of the lever *n* pivoted at *o*. The handhole cover *p*, when removed, permits access to the hubs of the inlet-valve and exhaust-valve levers in case their lubricators require attention. The igniter rod *q* actuating the movable electrode is connected to the eccentric pin *r* attached to the disk *s* that is held to the spur gear *c* by two bolts. The disk *s* is provided with slots to permit the igniter to be set so that the electrodes separate and produce the spark at the proper moment of the cycle. Fig. 7 also shows the crank-disks *t* and *u*, which have counterweights fastened to the cranks for the purpose of counterbalancing the reciprocating parts of the engine. Sight-feed lubricators *v* and *w* are mounted on a frame *x*, and supply oil to the main crank-shaft bearings and to the crankpin. The latter receives its lubrication by means of a wiper attached to the connecting-rod, which is brought in contact with the tip of the stationary cup *w* at every revolution of the crank-shaft.

19. Governing Mechanism.—Fig. 8 illustrates the governor and the attachments by means of which it acts on the fuel valve. As will be seen, the governor shaft *a* is driven from the spur gear *b* on the cam-shaft through the governor pinion *c*. Any increase in the speed of the engine due to a decrease in the load causes the governor flyballs *d*, *d*

to fly apart and move the governor sleeve *e* toward the pinion *c*. The end of the sleeve will then push against the roller *f* on the end of the governor lever *g* pivoted at *h*, so that the longer arm of the lever will move the notched block *i* swinging on the pin *j* out of the path of the blade *k* attached to the gas-valve lever *l*. Consequently, the lever *l*, while being pushed back by the gas cam attached to the large gear *b*,

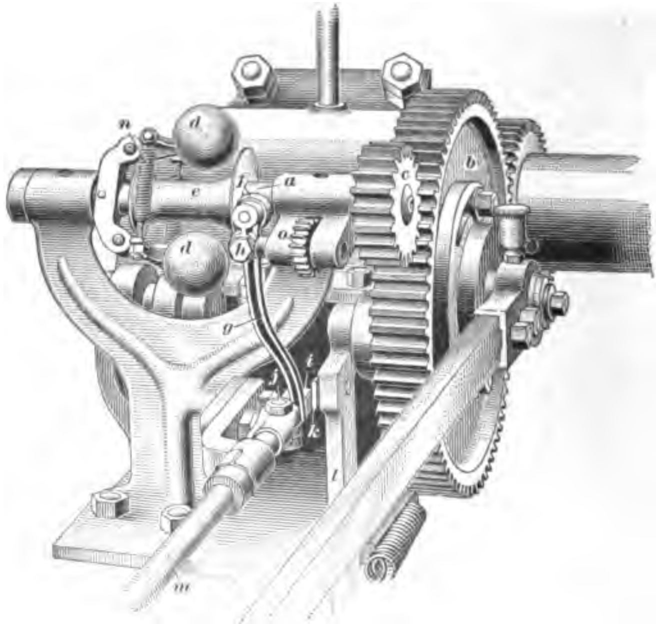


FIG. 8

will miss the block *i*, and the horizontal push rod *m* will remain stationary. On the other hand, if the load becomes heavier and causes the speed of the engine to fall below the normal, the governor balls will move inwards toward the spindle, and the sleeve will move to the left. A flat spring pressing against the side of the notched block *i* will push this block over so as to cause it to engage with the blade *k*, and the fuel valve will be opened by the lever *l* and the push rod *m*.

The resistance against which the governor flyballs must work is adjusted by the tension of the springs *n*, by means of which the speed of the engine is regulated. The nurled nut *o* serves to turn a threaded pin carrying the fulcrum *h* of the governor lever *g*, by means of which the roller *f* will be brought nearer to or withdrawn from the governor sleeve *e*. In this way, the speed of the engine can be varied within a certain range while the engine is running.

20. Igniter and Inlet Valves.—Details of the igniter are illustrated in Fig. 9, showing the inlet valve complete, with the front wall partly removed. In this igniter there are

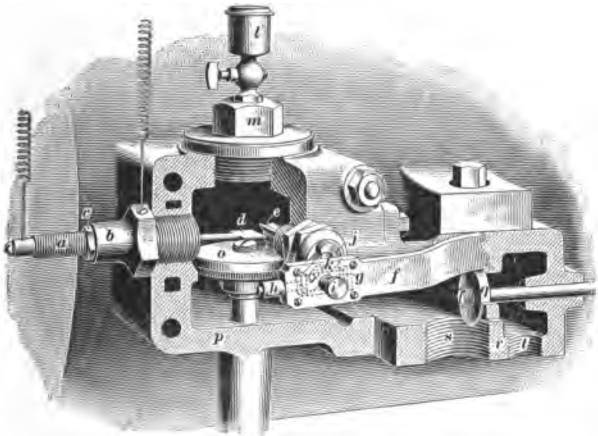


FIG. 9

two electrodes, one of which is stationary and the other revolves. The stationary electrode consists of a threaded pin *a* in a bushing *b*. A porcelain insulator, held in place by the locknut *c*, surrounds the pin *a* and insulates it from the bushing *b* into which it is fitted. A hardened and tempered flat steel spring *d* forms the contact point of this electrode. The revolving electrode *e* is provided with a hardened-steel blade that comes in contact with the spring *d* of the fixed electrode at every revolution of the cam-shaft. The head of the igniter rod *f* contains a sliding block, shown dotted at *g*, that can be moved back and forth by the nurled setscrew *h*

and tightened by the screw *i*. The small crank *j*, attached to the outer end of the revolving electrode *e*, engages a pin *k* in the sliding block *g*, indicated by dotted lines. The crank *j* is provided with a spring catch so that it will revolve the electrode *e* only when turning in the one direction. When turning backwards, the catch does not engage the electrode, and the crank *j* simply revolves around the stem of the electrode.

21. In order to give the small crank *j* the proper movement, the igniter rod is supported by the bearing shown at *y*, Fig. 7, oscillating on a pin fastened to the side of the cylinder. The position of the bearing is such that, with the given eccentricity of the pin *r*, Fig. 7, the head of the rod *f*, Fig. 9, will have an elliptic movement, the pin *k* sliding in the slot of the crank *j* while the crank revolves. The contact between the steel blade *e* and the stationary steel spring *d* is of a wiping nature, tending to remove from the points of contact the result of corrosion or deposits of carbon. The wear that naturally takes place while the electrodes are in operation can be taken up by turning slightly the slotted disk *s*, Fig. 7, in the slots provided for this purpose.

22. The point at which the spark is produced can be retarded while starting by changing the position of the sliding block *g*, Fig. 9, by means of the nurled screw *h*. In this way, the spark will not be made until after the crankshaft has passed the inner dead center, thus guarding against turning backwards. As soon as the engine has received a few impulses and gets under way, the sliding block is moved back so as to effect the earlier ignition required to develop the maximum power of the engine.

Fig. 9 also shows a small priming, or starting, cup *l* attached to the inlet-valve cap *m*. In case of difficulty in starting while the engine is being turned slowly by hand, this cup can be used for supplying a small quantity of gasoline to the combustion chamber; the gasoline is vaporized by the incoming air, and forms a powerful mixture to give the initial impulse to the engine. The inlet valve is shown at *o*

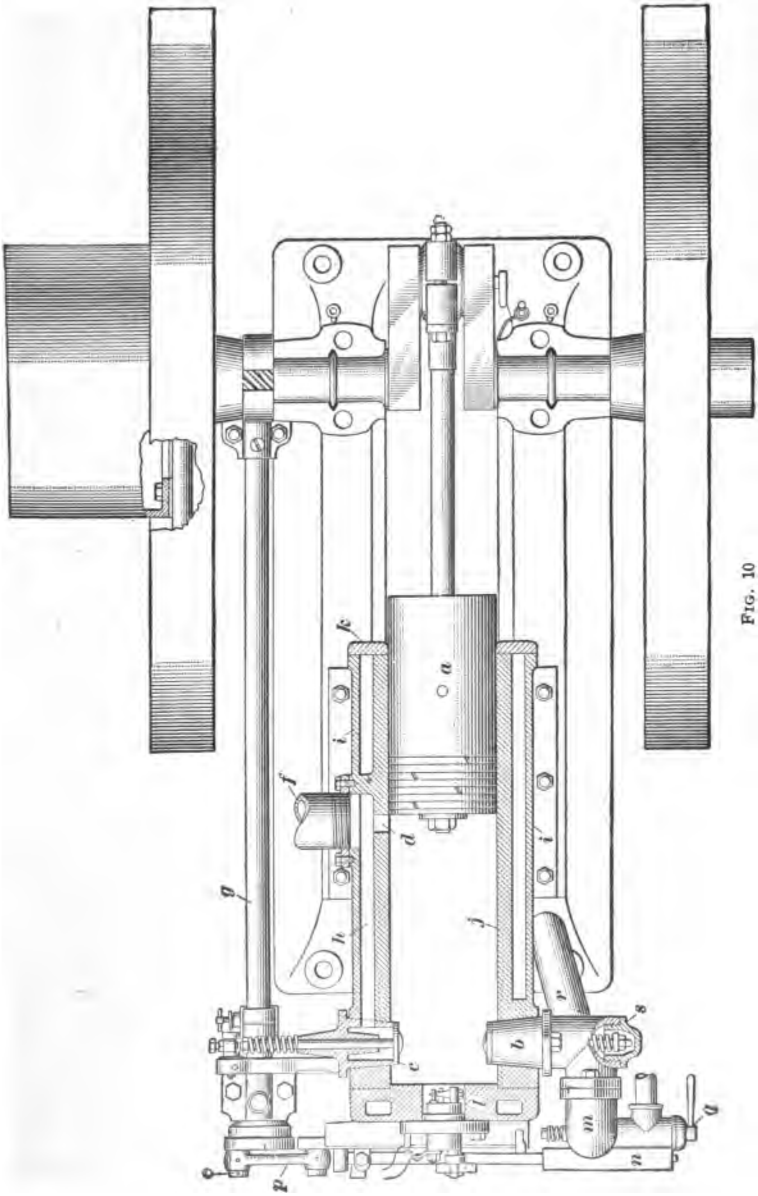


FIG. 10

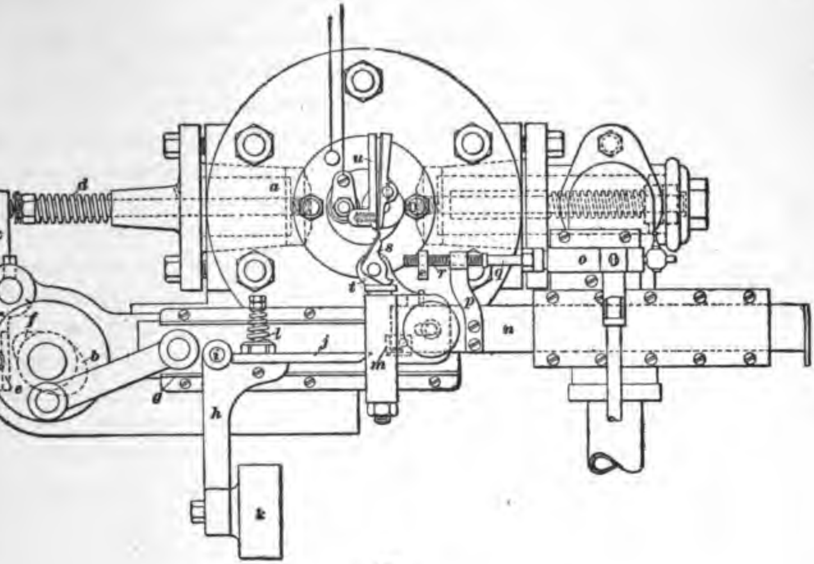
within the casing *p*, Fig. 9. The gas-valve casing *p* containing the gas valve *q*, is attached to the side of the main casing *r*, the air entering through a pipe screwed into the casing at *s*, and the gas coming through a pipe screwed into the casing at *t*. The air and gas are thoroughly mixed while passing into the cylinder through the inlet valve and port.

GAS ENGINE WITH PENDULUM, OR INERTIA, GOVERNOR

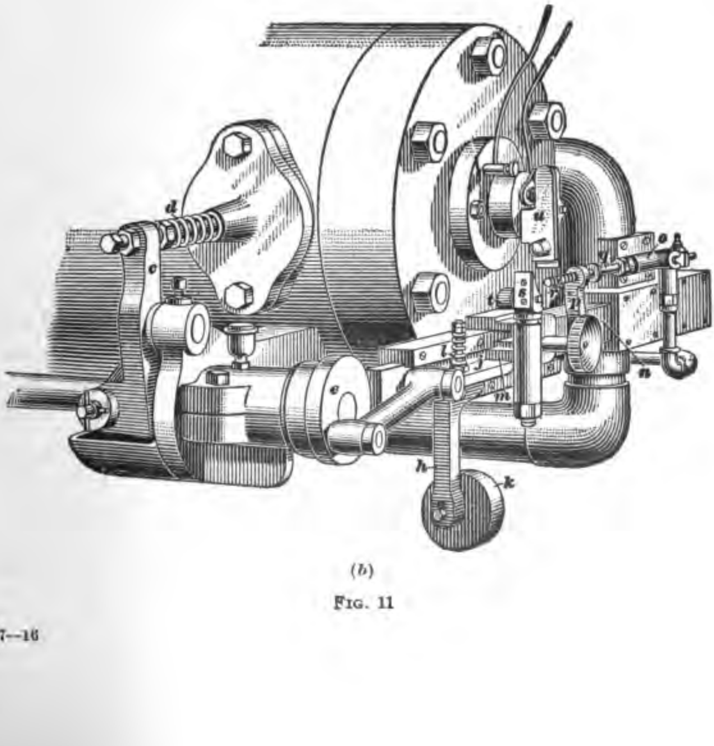
23. Another four-cycle horizontal engine of the first class, in which the governor controls the fuel supply, is shown in the horizontal sectional view, Fig. 10. The exhaust gases escape, in part, through a port in the cylinder wall, while the remainder are forced through a poppet valve. The figure shows the piston *a* at the end of the second forward, or expansion, stroke of the cycle, both inlet valve *b* and exhaust valve *c* being closed.

The piston has just uncovered the port *d* in the side of the cylinder wall, allowing a large portion of the exhaust gases to be expelled. The pressure in the cylinder at the end of the expansion stroke, before the port *d* is uncovered by the piston, is approximately 30 pounds per square inch of the piston area. Hence, when the port *d* opens the combustion chamber to the atmosphere through the exhaust pipe *f*, the burned gases escape and the pressure in the cylinder is reduced to practically that of the atmosphere. During the exhaust stroke of the piston, the remainder of the exhaust gases in the cylinder are swept out into the atmosphere through the exhaust valve *c*, which begins to open as soon as the piston starts on the exhaust stroke. The exhaust valve is opened by means of a cam on the secondary shaft *g*. The gases passing through the exhaust valve *c* travel through the port *h*, which is alongside the cylinder and communicates with the exhaust pipe *f*.

24. Inlet and Exhaust Valves.—As shown, both exhaust and inlet valves are placed in conical casings inserted in the cylinder. The outer jacket *i* enclosing the cooling-water space is cast in one piece with the cylinder *j*



(a)



(b)

FIG. 11

and closed at the crank-shaft end by a plate *k* and at the opposite end by the cylinder head *l*. The fuel valve *m*, which is of the poppet type, is attached to the inlet-valve casing *b*, and is operated by a slide *n* driven by an eccentric pin *o* and a connecting-rod *p* from the end of the cam-shaft *g*. The amount of gas admitted is regulated by the throttle cock *q*.

The air enters the inlet valve through the pipe *r* communicating with the space under the engine bed. The inlet valve *b* is fitted with a steel poppet having a light coil spring that tends to hold the valve on its seat, but that permits the suction caused by the forward movement of the piston to open the valve automatically during the first outward, or suction, stroke of the cycle. A cap *s*, attached to the outer end of the inlet-valve casing *b*, tends to reduce the noise caused by the closing of the inlet valve when striking its seat.

25. Further details of the valve mechanism, as well as the governing and ignition devices, are shown in the end elevation and perspective end view of the cylinder head, Fig. 11 (*a*) and (*b*). The mechanism actuating the exhaust valve *a* consists of the cam *b*, the rocker-arm *c*, and the coil spring *d*. Setscrews and locknuts admit of taking up any wear or accidental bending of the rocker-arm *c* caused by the sticking of the valve in its casing. A hardened-steel plate, shown dotted at *e*, is attached to the lower end of the rocker-arm *c* and tends to reduce the wear at this point. To make it easier to start the engine, an auxiliary exhaust cam *f* permits the valve to open partly during the compression stroke, and allows a portion of the compression pressure to escape through the exhaust valve *a*. It must be understood, of course, that the cam-sleeve carrying the two cams *b* and *f* can be shifted longitudinally on the cam-shaft, so that, in starting, both cams engage the rocker-arm *c*; while, during regular running, or as soon as the engine comes up to speed after starting, the sleeve is moved back, so that the valve is affected by the main-exhaust cam *b* onlv.

26. Governing.—The governor of this engine, which controls the fuel valve on the hit-or-miss principle, is of the pendulum, or inertia, type, and is attached to the slide *g*. The governor consists of the lever *h*, which is pivoted on the pin *i*, and is fitted with the blade *j* attached to the horizontal arm of the lever *h*, the weight *k* at the end of the vertical arm of the lever, and the coil spring *l*. The spring *l* permits the speed of the engine to be adjusted by increasing or diminishing its tension, by means of a nut and locknut. A notched steel block *m* is attached to the horizontal slide *n*, by means of which the gas is admitted to the mixing chamber *o*. The arm *p* is connected to the stem *q* of the valve that regulates the amount of gas supplied with the air to make the proper mixture. The point at which the arm *p* is connected to the stem *q* is adjusted by a regulating screw *r*, which determines the lift of the valve and thereby the quantity of fuel admitted.

27. If the speed rises above the normal, the inertia of the weight *k* causes the lever *h* to swing on its pivot *i*, so that the point of the blade *j* is lowered and passes under the notched block *m* and the gas-admission device remains closed, only pure air being drawn into the cylinder and exhausted through the exhaust port and valve. As soon as the speed decreases, the point of the blade *j* is raised and engages the notched block *m* opening the gas valve.

The igniter is operated by the dog *s*, which is attached to the frame *t* fastened to the slide *n*. The igniter plug and electrodes *u* are of the same general design as other make-and-break contact igniters. The igniter mechanism, being connected with the slide *n*, is put out of action whenever the governor causes the blade *j* to miss the block *m*, so that, when no gas is admitted, the ignition is also prevented from producing a spark.

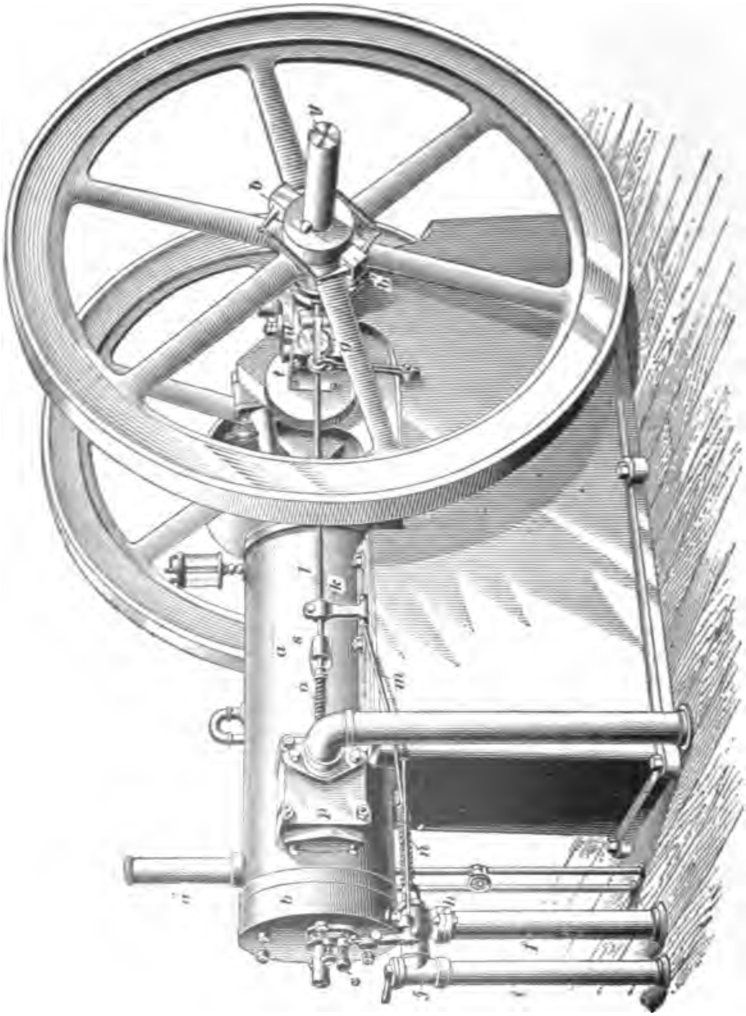


FIG. 12

ENGINES WITH HIT-OR-MISS CONTROL OF EXHAUST VALVES

GAS ENGINE WITH FLYWHEEL GOVERNOR

28. An engine of the second class, regulated on the hit-or-miss principle, with the governor acting on the exhaust valve, is illustrated in Figs. 12 and 13, Fig. 12 showing a full side view and Fig. 13 (*a*) a horizontal section. The bed of this engine is high enough to make it unnecessary to carry the foundation above the floor level in order to have the fly-wheels clear the floor. The cylinder, shown at *a*, Fig. 12, is bolted by flanges to the bed. The water-jacket and cylinder are cast as one piece; the inner end, nearest the crank-shaft, is fitted with a ring that closes the water space, and the other end is closed by the cylinder head *b*. The water-jacket of the cylinder head communicates with the water-jacket of the cylinder.

The inlet valve, shown at *c*, Fig. 13 (*a*), is located in the center of the cylinder head *b*, is opened automatically owing to the partial vacuum produced by the motion of the piston *d*, during the suction stroke, and is closed by the tension of the coil spring *e*. The air supply is taken from outside through the pipe, shown at *f*, Fig. 12, attached to the bottom of the cylinder head immediately below the space, shown at *g*, Fig. 13 (*a*), back of the inlet-valve seat.

29. The gas-supply pipe *i* is connected to a T-shaped fitting, shown at *h*, Fig. 12, in the air pipe at the bottom of the cylinder head, where the gas mingles with the air before entering the combustion chamber. The gas-supply pipe carries at its top the gas-throttle cock *j*, which is fitted with a handle and dial by means of which the amount of gas admitted can be regulated. The fitting *h* contains a poppet valve that is opened by means of the arm *k*, fastened to the exhaust-valve push rod *l*, and connected to the valve by the connecting-rod *m*. On the return stroke of the push rod, the gas valve in the fitting *h* is closed by the action of

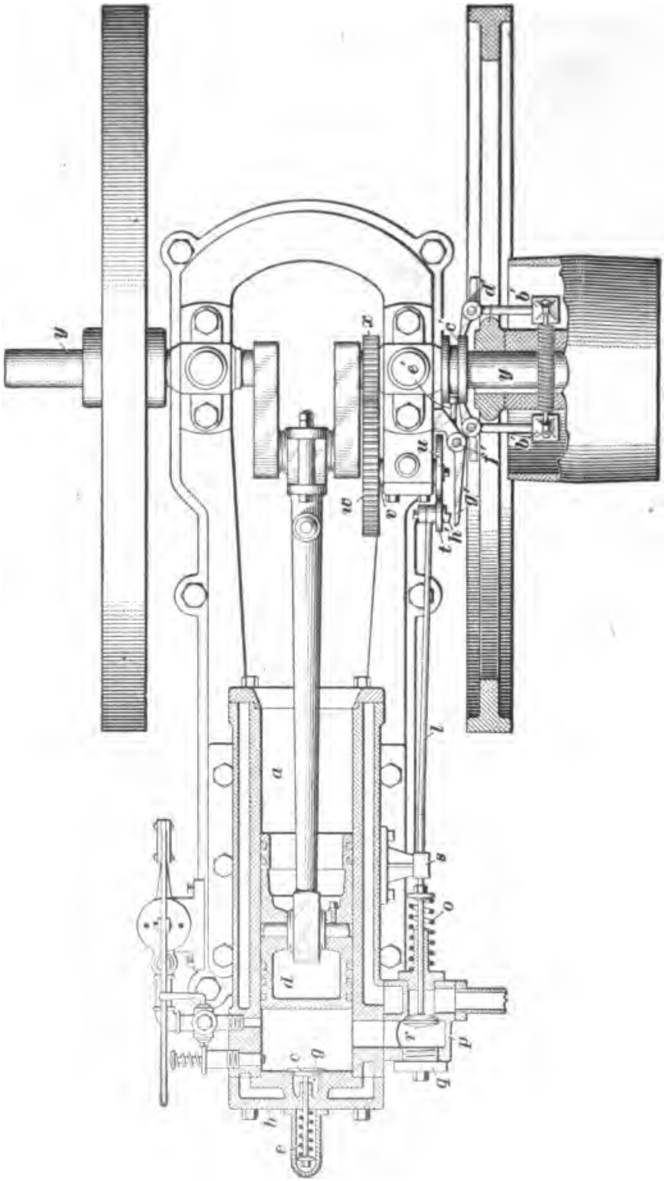


FIG. 13 (a)

the coil spring *n*. The opening of the inlet valve is timed by the adjustment of the connecting-rod *m*, so as to occur after the exhaust valve has been closed by the exhaust-valve spring *o*.

The exhaust-valve casing *p*, Fig. 13 (*a*), bolted to the side of the cylinder, is closed by the cap *q*, and contains the horizontal exhaust valve *r*. The exhaust valve is opened by the push rod *l*, which is supported at one end by the bracket *s*. The other end of the rod is carried by a roller *t* supported on a forked link. The roller and link are rocked forwards by the cam *u*, on the end of the valve shaft *v*, and is driven by the gears *w* and *x* from the crank-shaft *y*. The push rod *l*, Fig. 12, has an extension and operates the electric igniter, shown at *z*, attached to the cylinder head. This igniter is of the make-and-break contact type already described.

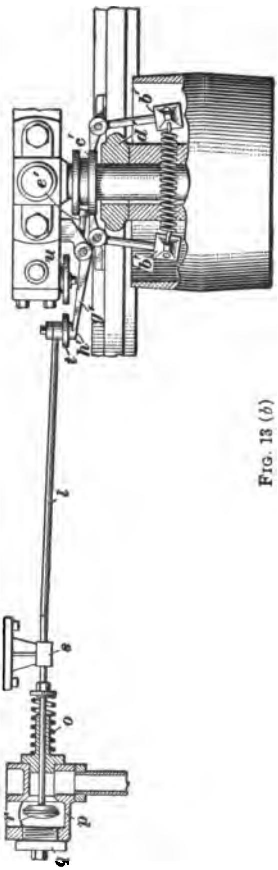


Fig. 13 (*b*)

30. Governing.—The governor of this engine is of the centrifugal type, and is connected to the flywheel, as shown in Fig. 13 (*a*) and (*b*). When the speed rises above the normal, the centrifugal force of the weights *b'*, *b'* throws them outwards. The arms of these weights, turning on their pivots, draw the movable sleeve *c'* closer to the flywheel hub *d'*. This motion of the sleeve causes the lever *e'* to swing on its stationary pivot *f'* and brings the end *g'* of the lever into line with a notch in the block *h'* outside of the roller *t* on the exhaust-valve push rod *l*. Consequently, the rod *l* is prevented from moving its full distance to the right, and the exhaust valve is held open, as indicated in Fig. 13 (*b*).

31. With the exhaust valve open during the suction stroke, a portion of the burned gases will be drawn back into the cylinder. There being no partial vacuum in the combustion chamber when the exhaust valve is thus kept open, the spring *e*, Fig. 13 (*a*), keeps the inlet valve closed, and no combustible mixture is admitted so long as the speed is above the normal. As soon as the speed drops, however, the governor flyballs *b′*, *b′* move closer toward the center of the shaft, and the governor sleeve *c′* is shifted back toward the main bearing, thus causing the point of the blade *g′* to be disengaged from the notch *h′*, and the exhaust valve is closed by the tension of the coil spring *o*.

While the speed of the engine is normal, the point *g′* of the governor sleeve *c′* remains in such a position as to permit the push rod *l* and the roller *t* to be carried past the point *g′*, thus allowing the exhaust valve *r* to come to its seat. As the spring *e* of the inlet valve *c* is much lighter than the spring *o* of the exhaust valve, the partial vacuum created in the cylinder by the suction stroke causes the inlet valve to be drawn open. The position of the governor at the normal speed of the engine is shown in Fig. 13 (*a*).

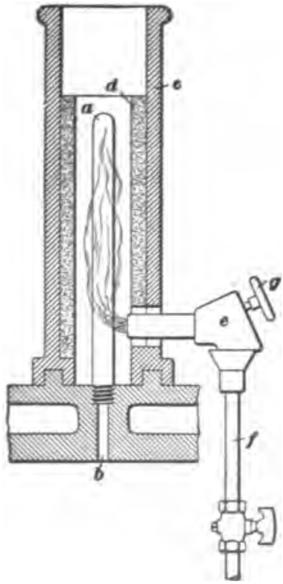


FIG. 14

32. Hot-Tube Igniter.—Besides the electric igniter, the engine is equipped with a hot-tube igniter, shown at *a′*, Fig. 12, attached to the top of the combustion chamber. A sectional view of this igniter is shown in Fig. 14. An iron or nickel-alloy tube *a* is screwed into the wall of the cylinder, and communicates with the combustion chamber by means of the hole *b*, the upper end of the tube being closed. The tube is surrounded by a cast-iron chimney *c*, lined with asbestos *d*,

the asbestos serving to concentrate the heat of the flame on the tube and protect the walls of the chimney. The tube *a* is heated by the burner *e*, to which gas is supplied by a pipe *f*. The air supply to the burner is regulated by the valve *g*. During the compression stroke, a portion of the combustible mixture in the cylinder is forced into the tube *a*, where it is ignited by the heat as the crank passes the dead center.

GASOLINE ENGINE WITH FLYWHEEL GOVERNOR

33. A gasoline engine of the same type as the gas engine just described differs from it but little and has the same general appearance. The difference between the two engines consists principally in the addition of a gasoline pump of the plunger type, with check-valves in the gasoline suction and discharge pipes, and in the arrangement for admitting and vaporizing the gasoline. The pump is operated from an eccentric pin attached to the cam-sleeve on the gear-shaft.

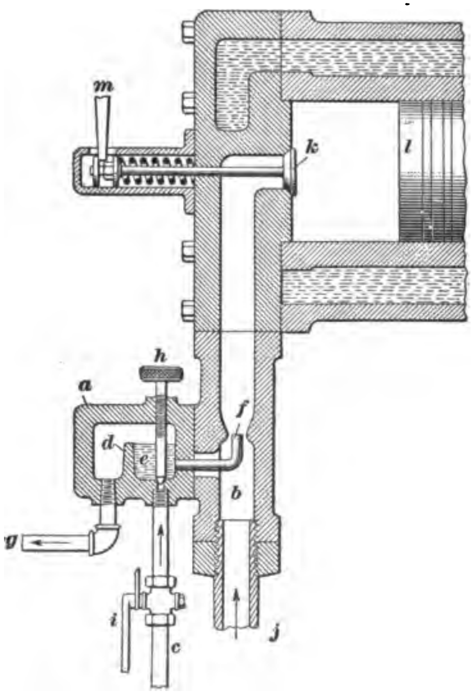


FIG. 15

The arrangement for admitting and vaporizing the fuel is shown in detail in the vertical section, Fig. 15. The gasoline-valve casing *a* is attached to the air-inlet casting *b*. Gasoline is pumped from the gasoline storage tank through the supply pipe *c* into the valve casing *a*. A

partition *d*, dividing the inner space of the valve casing into two compartment, keeps the gasoline at a constant level in the compartments *e*, slightly below the upper end of the nozzle pipe *f*. The excess of gasoline delivered by the pump returns to the tank through the overflow pipe *g*. A threaded needle valve *h* regulates the gasoline admitted to the compartment *e* and the nozzle pipe *f*, while the dial cock *i* serves to shut off the supply when stopping the engine.

34. The air enters the passage leading to the inlet valve, shown at *k*, through the air pipe *j*. At the point where the nozzle pipe *f* is inserted, the area of the air passage is reduced so as to create a high velocity of the air-current. This results in a strong suction that draws a proportionate quantity of gasoline through a small hole in the upper end of the nozzle *f*. The volatile fuel is thus atomized by the air-current and passing upwards reaches the cylinder as a combustible mixture of air and gasoline vapor. When drawn into the cylinder, the mixture is compressed by the piston *l* on the following inward stroke, burned and expanded during the working stroke, and the products of the combustion expelled as usual, completing a cycle of operations.

35. Owing to the strong suction through the inlet valve, there is a possibility, especially if the inlet-valve spring should become weakened, that the inlet valve may chatter or open to a slight extent, even when the exhaust valve is held open by the governor, while the engine is running under light load. This results in a waste of fuel, as the charge drawn into the cylinder forms too weak a mixture to explode, and is expelled, unburned, through the exhaust pipe. To prevent this, the push rod that opens the exhaust valve and is controlled by the governor has an arm or extension that is connected to the lever *m*. When the governor causes the exhaust valve to be kept open, the lever *m* is moved to such a position that it prevents the washer on the end of the inlet valve from moving inwards, thus positively locking the inlet valve and preventing it from being even slightly opened.

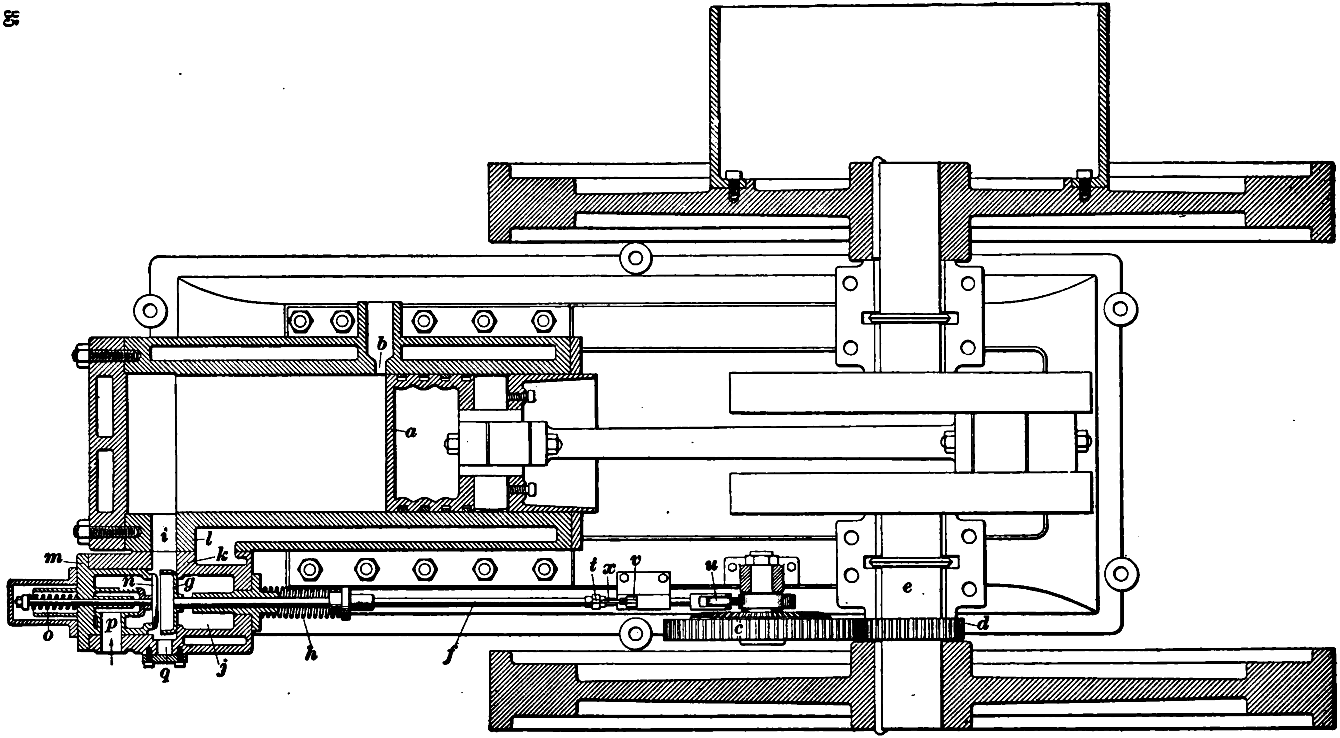


FIG. 16 (a)

GAS ENGINE WITH CENTRIFUGAL GOVERNOR

36. General Construction.—The general construction of another gas engine of the second class is shown in the sectional plan view, Fig. 16 (*a*). This engine combines the principle of governing the exhaust valve, by holding it open during the idle strokes, with that of the auxiliary or double exhaust. As shown, the piston *a* has reached its outer position, having uncovered the exhaust port *b* in the side of the cylinder wall and permitting the major portion of the products of the combustion to escape through this port. The pressure in the cylinder, which immediately before the opening of the port *b* is about 30 pounds per square inch, is thus reduced to a few pounds above that of the atmosphere.

The exhaust cam is attached to the spur gear *c*, driven by the pinion *d* on the crank-shaft *e*. On the second stroke of the piston, the exhaust cam pushes against a roller *u* on the end of the horizontal push rod *f*, and opens the exhaust valve *g* against the pressure of the coil spring *h*. The remainder of the exhaust gases is then expelled through the port *i*, during the return stroke, into a pipe extending downwards from the space *j*, and leading to the open air. The exhaust port *b* is connected by a pipe to a T in the pipe attached to the exhaust chamber *j*, so that the exhaust gases are all carried off through a single pipe.

37. The valve casing *k*, attached to the side of the cylinder *l*, and connected to the combustion chamber by the port *i*, contains, besides the exhaust valve, a casing *m*. This casing forms the inlet valve with a poppet valve *n* held on its seat by the coil spring *o*, and opened automatically by the partial vacuum in the cylinder during the suction stroke of the piston. The air enters the casing *m* through a pipe attached to the bottom of the outer casing *k*, in line with the horizontal port *p*, to which the gas-supply pipe and gas-throttle cock are attached. The port *q* opposite the exhaust valve is closed by means of a handhole cover, and serves for the purpose of examining the condition of the valves.

38. The Governing Mechanism.—The governor of an engine of this class is shown in Fig. 16 (*b*), and is of the centrifugal flyball type; it is operated, by means of a pair of bevel gears, from the cam-shaft that carries the large spur gear *c*. If the speed of the engine increases under light load, the centrifugal force of the balls causes them to fly apart, and in so doing they lower a spindle that passes through the hollow governor shaft and presses on the lever arm *r* pivoted at *v*. This lever in turn acts on the two-arm lever *s* pivoted

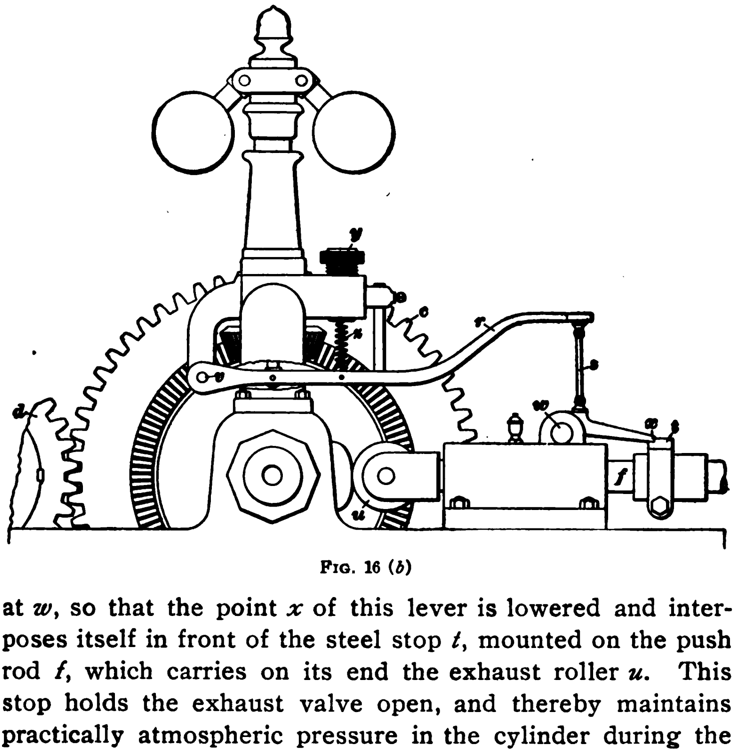


FIG. 16 (*b*)

at *w*, so that the point *x* of this lever is lowered and interposes itself in front of the steel stop *t*, mounted on the push rod *f*, which carries on its end the exhaust roller *u*. This stop holds the exhaust valve open, and thereby maintains practically atmospheric pressure in the cylinder during the suction stroke. The inlet valve *n*, Fig. 16 (*a*), will then remain closed, and no charge will be admitted until the speed of the engine falls sufficiently to permit the governor balls to fall and cause the lever arm *x*, Fig. 16 (*b*), to be withdrawn from its position in front of the stop *t*.

The speed of the engine can be regulated by means of the hand nut *y* and the coil spring *z* fastened to the lever *r*. By turning the hand nut to the right or left, the tension of the spring *z* is increased or diminished so as to vary the point at which the exhaust valve remains open, and consequently to increase or diminish the speed of the engine.

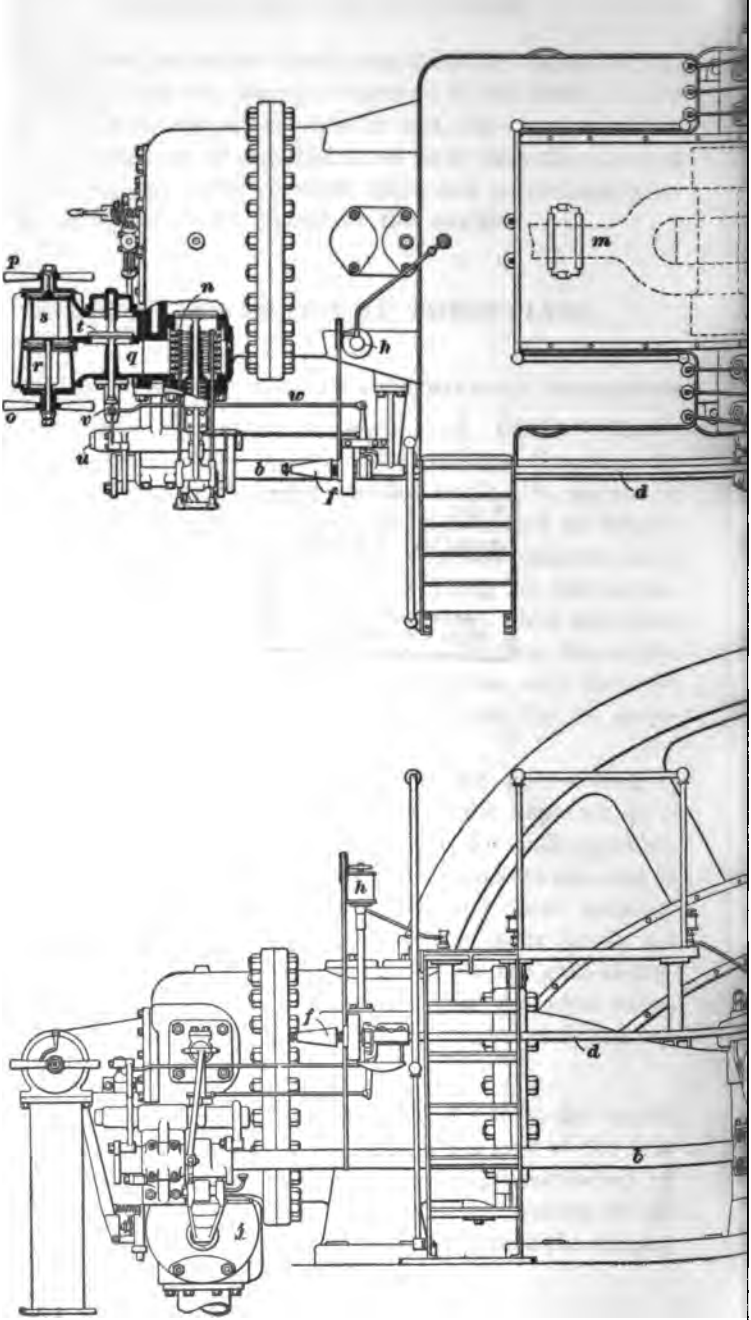
ENGINES GOVERNED BY THROTTLING

GAS ENGINE WITH HORIZONTAL CENTRIFUGAL GOVERNOR

39. Double-Cylinder Engine.—A double-cylinder engine of the third class, in which the governor throttles the mixture according to the load on the engine, is shown in Figs. 17 and 18. In these figures is represented an engine of 300 horsepower, the cylinders being placed opposite each other, with the two connecting-rods working on one crank. One of the rods has a single center bearing, while the other rod has a forked end, with two bearings straddling the center bearing. Fig. 17 is a plan view of the engine, with the inlet valves at one end shown in cross-section, while Fig. 18 shows a side view.

A pair of spiral gears, contained in the gear-casing *a*, drives the two cam-shafts *b*, *c*, as well as the separate governor shafts *d*, *e*. The governors *f*, *g*, one for each cylinder, are of the centrifugal type. The cylinder jackets are cast in one piece with the main engine bed, and have external flanges to which the outer shells of the cylinder heads are bolted. Belt-driven oilers *h*, *i*, operated from the cam-shafts, convey lubricating oil to the pistons. In the plan view, Fig. 17, the arrangement of the crank is shown at *k*, and the connecting-rods at *l* and *m*.

40. The method of admitting air and gas to the cut-off valve *n* is shown in the sectional view at the end of the left-hand cylinder. Both gas and air can be proportioned by manipulating the hand levers *o*, *p* to suit the quality of the fuel available in individual cases. The air enters the mixing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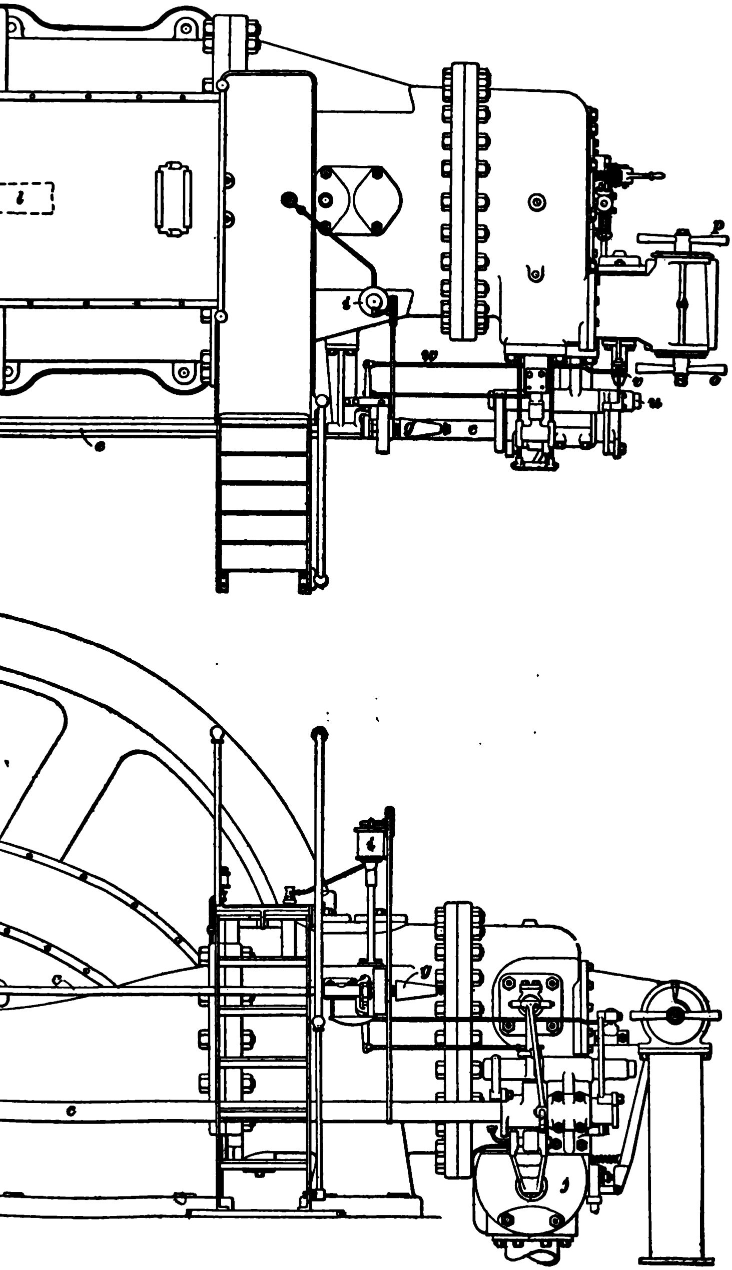


chamber *q* directly from the casing *r*, while the gas is admitted from the casing *s* through a poppet valve *t*, operated by a cam and lever from the cam-shaft. The exhaust-valve casings *j*, Fig. 18, are placed below the cylinder heads, both being equipped with horizontal poppet valves.

41. Inlet Valve.—Fig. 19 shows the cut-off valve in front and side elevations and in sectional plan. The valve casing *a* contains the main admission valve *b*, which is opened

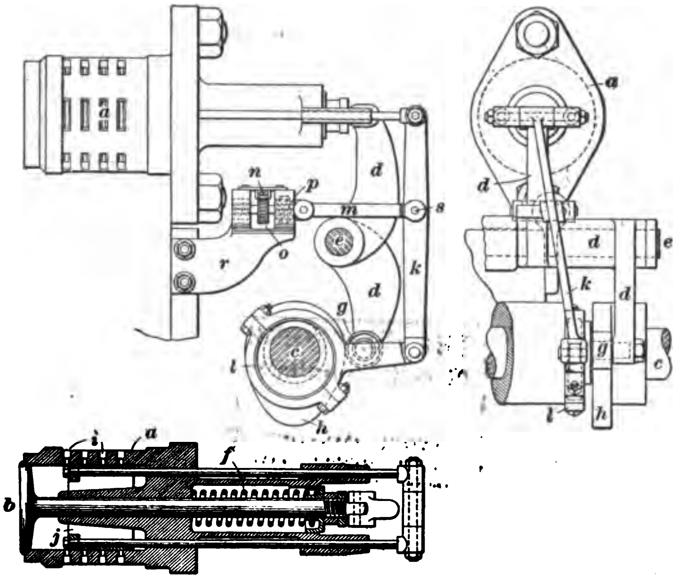


FIG. 19

by a cam on the shaft *c*, and a bell-crank lever *d* pivoted at *e*. This main poppet valve is always opened to the same extent, its stroke or lift being the same under all conditions of load. The spiral spring *f* forces the valve *b* on its seat after the roller *g* has passed the cam *h*. The body of the valve casing *a* has a number of ports *i*, through which the mixture passes to the interior of the valve through similar ports in the cut-off sleeve *j*, which fits snugly in the casing. The cut-off sleeve is operated independently of the main admission valve by the rocker-arm *k* and the eccentric *l*.

42. Governing.—The point of cut-off, which regulates the quantity of mixture admitted to the cylinder, is changed by the action of the governor in accordance with the amount of work performed by the engine. As soon as the speed fluctuates, the governor will move the rod *m*, Fig. 19, by means of the rack *n* and the pinion *o* turning the screw *p*, thereby moving the rod *m* in or out, according to the load. A larger view of this rack and screw is shown in Fig. 20. One end of the screw *p* turns in the nut *q*, which is supported by the bracket *r*, and is fastened to the side of the cylinder head. The other end of the screw turns in a nut on the end of the rod *m*, Fig. 19, thus moving the rod when the pinion *o* is rotated. The movement of the rod *m* changes

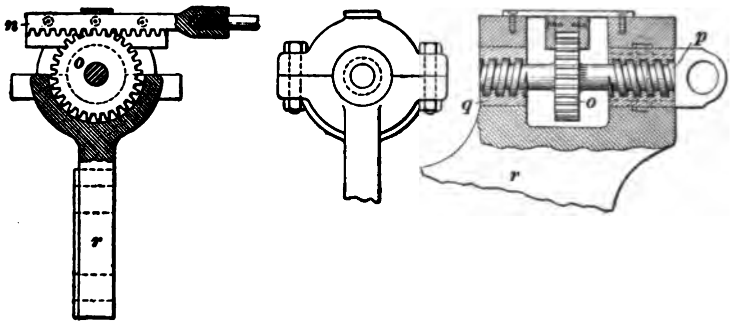


FIG. 20

the position of the pivot pin *s* of the rocker-arm *k*, and alters the point of the cut-off by regulating the relative position of the ports in the valve casing *a* and the cut-off sleeve *j*.

43. The method of regulation just described controls the speed of the engine throughout a range of loads from the maximum to about one-third load. Whenever the load falls below this point, the throttling method of regulation is automatically changed to the hit-or-miss method in the following manner: The bell-crank *u*, Fig. 17, operates the gas valve through a steel block *v* interposed between the crank-arm *u*, and the end of the stem of valve *t*. Whenever the load falls below one-third of the maximum, the governor withdraws the block *v* from its operative position between the arm *u*

and the end of the stem of valve *t*, by means of the governor rod *w*, and the gas valve remains closed. The admission valve, however, is operated as usual, admitting pure air only during the idle strokes. The steel block *v* is made adjustable, so that, in the two-cylinder engines, it is possible to equalize the work done by each cylinder by changing the block at intervals, causing one cylinder to carry the greater portion of the load while being regulated by the throttling method, and the other to operate on the hit-or-miss principle. At intervals, the adjustment is reversed, giving the first cylinder a chance to take care of the light end of the load and have the benefit of occasional cool charges of pure air.

44. Cylinder and Cylinder-Head Castings.—Owing to the great amount of heat generated in the combustion

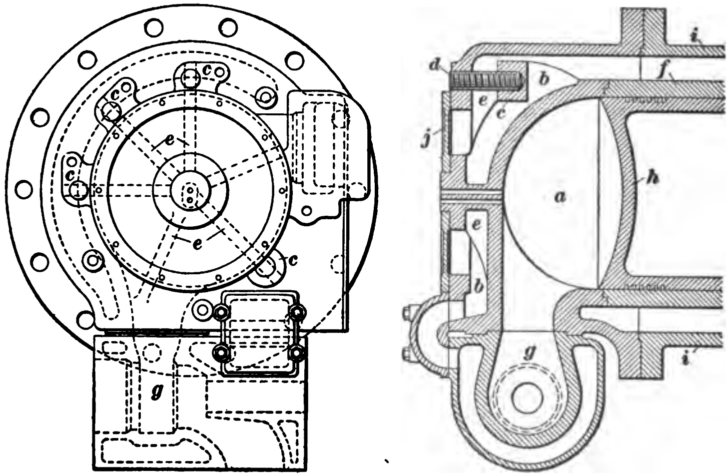


FIG. 21

chamber of the larger types of gas engines, such as the one shown in Figs. 17 and 18, special care must be exercised in the design of the cylinder head to avoid any unequal shrinkage of the casting that might cause trouble after the engine is put in operation. The end and sectional views of the head shown in Fig. 21 illustrate the precautions that have been taken to guard against difficulties of this nature. It

will be observed that the inner walls of the combustion chamber *a* have very little direct connection with the jacket walls enclosing the water space *b*, except where the metal surrounding the valve ports connects the two walls. For the purpose of securely tying the walls together, lugs *c*, *c* are provided in suitable places, and staybolts *d* are fitted so as to hold the outer jacket walls to the lugs. The lugs are braced and connected to the two walls by ribs *e*, *e*.

This arrangement of the cylinder head permits the inner walls of the combustion chamber to expand without greatly affecting the cooler walls surrounding the water space. The sectional view also shows the liner *f* that forms the working cylinder, the exhaust-valve casing *g*, the end of the piston *h* in its innermost position, and the cylinder jacket *i* with a flange corresponding to the flange of the cylinder head. The end of the cylinder head is closed by a cover-plate *j* that can be removed for cleaning the water space if necessary. This plate is purposely made much lighter than the walls of the cylinder or cylinder-head water-jacket, so that, in case water is accidentally left in the jacket in cold weather, the plate will burst if the water freezes, thus affording a relief for the pressure and a safeguard against damage to the cylinder or cylinder head.

45. Exhaust Valve.—Fig. 22 shows the construction of the exhaust valve, which is of the horizontal poppet type. The valve is made in the shape of a hollow casting, as shown at *a*. One end has a piston extension *b*, fitted in the exhaust-valve cover and packed with metal packing rings of the usual type. The port *c* through the valve permits the pressure on the outlet side of the valve seat *d* to be equalized with that on the other side of the piston *b*. The only unbalanced pressure that tends to hold the valve to its seat is that of the exhaust against the excess of area of the seat *d* over that of the piston *b*; otherwise, the valve is balanced.

The body of the valve, as well as the stem, is hollow, for the purpose of being cooled by a supply of water that enters the valve through the stationary tube *e*, passes into the valve

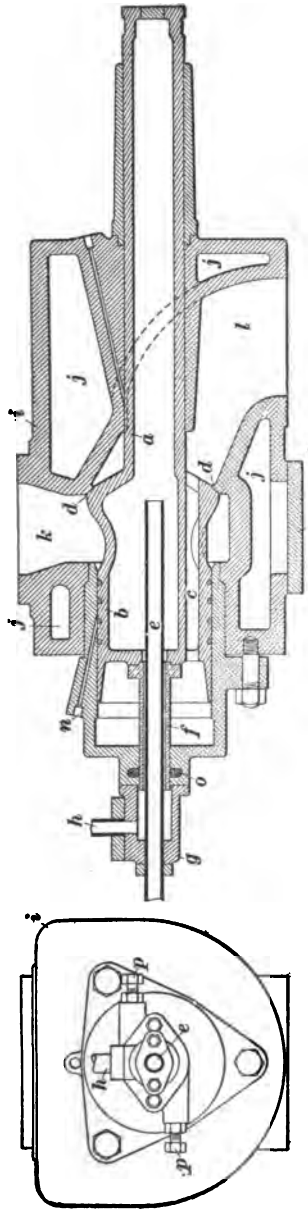


FIG. 22

body, and out through the space between *e* and the extension *f* of the valve to the hollow cap *g*, and thence out through the overflow pipe *h*. The extension *a* and the piston *b* act as guides to keep the valve in position, so that it will come to its seat properly when closed after being opened by the cam on the cam-shaft.

46. The valve casing *i* is also water-cooled, being provided with a water space *j*, *j* around the walls forming the port *k*, which communicates with the combustion chamber. The outlet port *l*, to which the exhaust pipe is connected, is also surrounded by the water space *j*. A handhole *m* can be opened for cleaning the water space of lime or similar deposits. The piston-shaped extension *b* is lubricated through the oil hole *n*, while similar provision is made for oiling the valve stems. The extension *f* is made water-tight by means of packing placed in the annular groove *o* and compressed by means of the tangentially arranged bolts *p*.

The electric ignition and the mechanism for operating it do not differ materially in this engine from the devices used on engines already described.

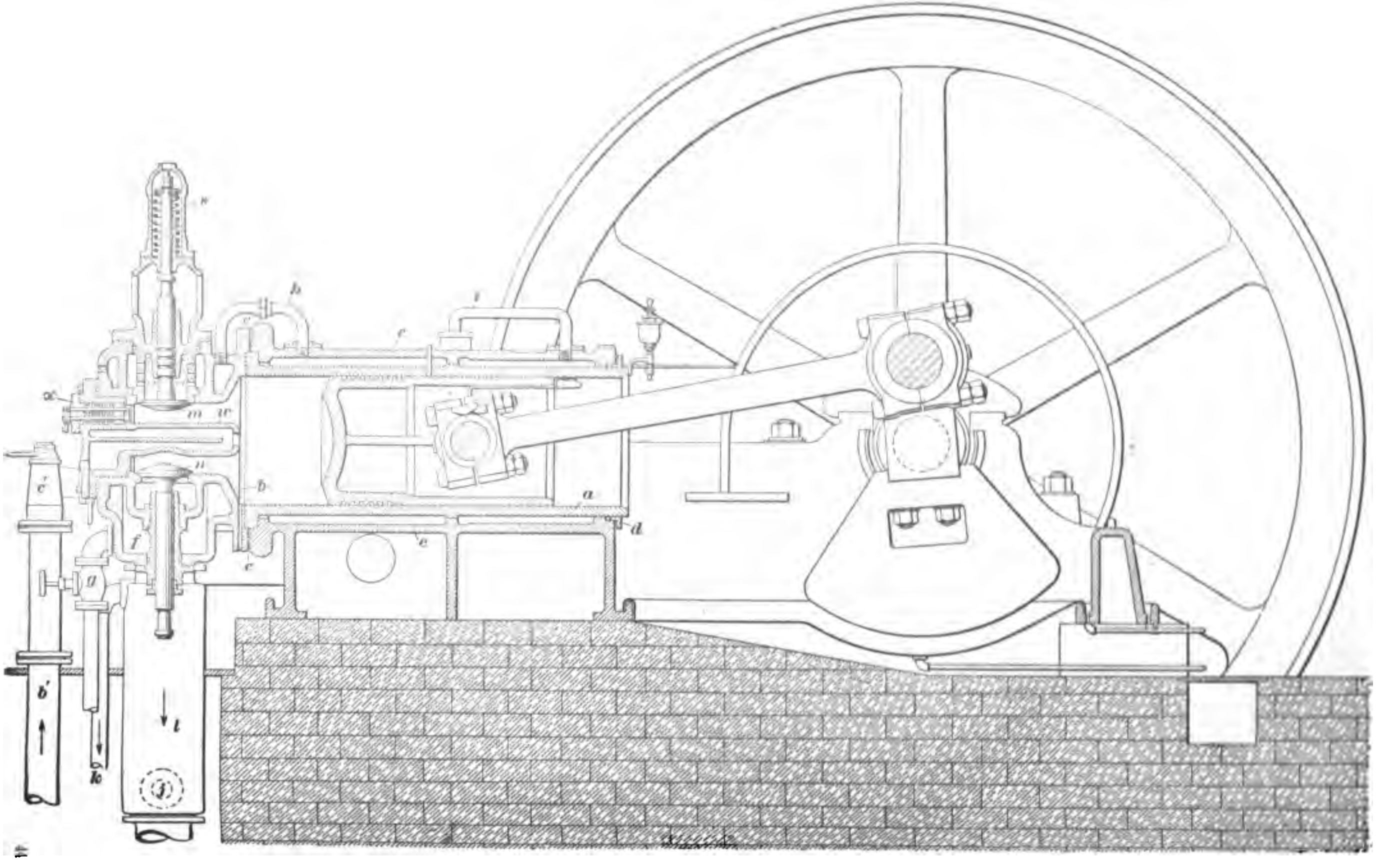


FIG. 23

GAS ENGINE WITH VERTICAL CENTRIFUGAL GOVERNOR

47. A four-cycle engine of the third class, with throttling governor, built principally in sizes above 100 horsepower, is shown in Figs. 23 and 24. Referring to

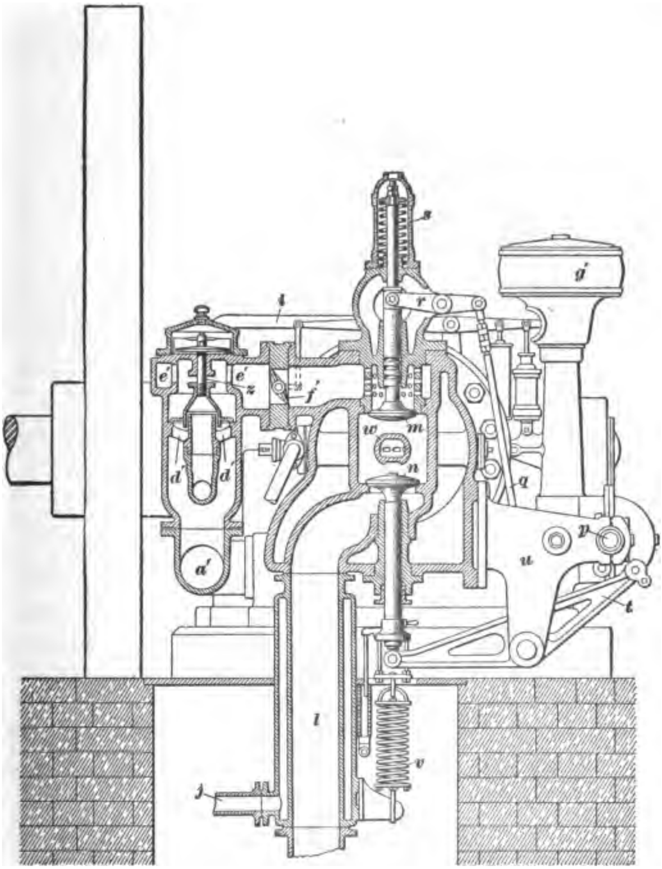


Fig. 24

Fig. 23, it will be seen that the bed of the engine and the water-jacket of the cylinder are one casting. The cylinder *a* is a liner inserted in the water-jacket and clamped in position by the cylinder head *b* with its flange against the flange of

the cylinder and fitting into a countersunk portion of the jacket at the joint *c*. The opening around the crank-end of the cylinder is closed, to prevent the escape of the water from the jacket, by a small stuffingbox *d* that allows longitudinal expansion of the cylinder. The cooling-water space in the cylinder jacket *e* has no direct connection with that in the cylinder head, the head-casting being closed by a solid wall on the side of the cylinder joint. The cooling water first enters the lower part *f* of the head through the regulating valve *g*, thence flows to the cylinder jacket through the pipe *h*, and is finally conducted to the drain through the outlet pipe *i*. A separate supply pipe *j* and overflow *k* cools the first section of the exhaust pipe *l*.

48. The cylinder head contains the inlet and exhaust valves, both being of the vertical poppet type. The inlet valve *m*, Figs. 23 and 24, is located above the exhaust valve *n*. The inlet valve is opened by a cam on the side shaft *p*, Fig. 24, a push rod *q*, and a lever *r*, and is closed by the spring *s*. The exhaust valve *n* is opened by a cam engaging a roller on the end of the lever *t* pivoted on the arm *u* and closed by the tension of the spring *v* fastened to the exhaust pipe *l*.

49. In order to use the highest possible degree of compression, a water-cooled cover and casing, shown at *w*, Fig. 23, is attached to the end of the cylinder head *b*, and extends well into the clearance space. This extension of the cylinder-head cover has a tendency to keep the temperature of the compressed charge comparatively low, and thus prevents the charge from being ignited by compression, even if gas of rich quality is used. The cylinder-head cover also contains the electric igniter plug *x*.

A double-seated mixing valve, shown at *z*, Fig. 24, and operated automatically by the partial vacuum created in the cylinder during the suction stroke of the piston, mixes the air and gas before they enter the cylinder through the main inlet valve *m*. The air is taken from the space under the engine bed, which is open to the atmosphere, and enters the mixing valve *z*, through the elbow *a'*. The gas is admitted

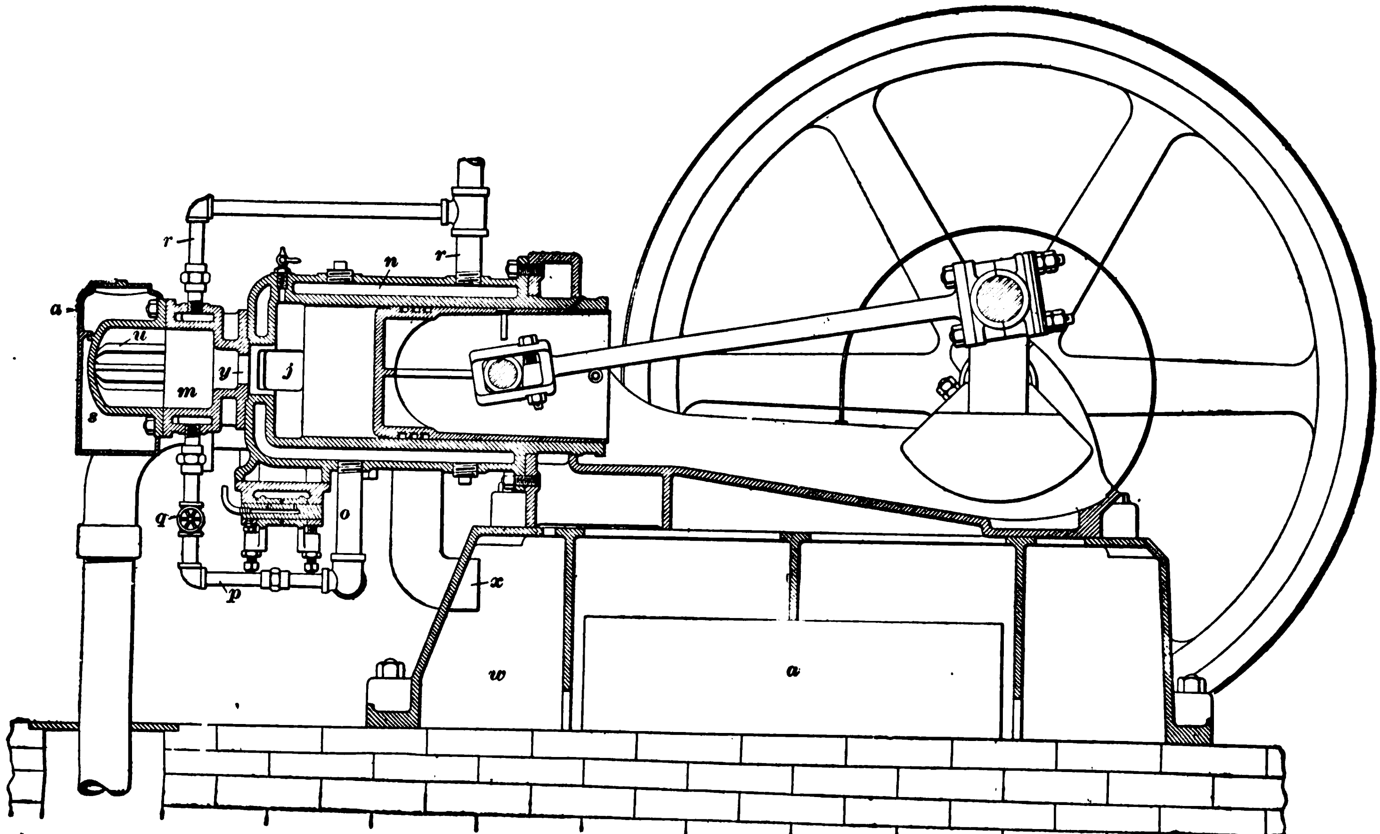
through the supply pipe *b'* and the throttle cock *c'*, Fig. 23, and is split up into a number of small streams. These streams flow into the air-current through ports *d'*, Fig. 24, in the mixing valve, after which the mixture passes through another set of ports *e'*, Fig. 23, as it leaves the mixing valve. This imparts a whirling motion to the mixture, so that the two constituents of the charge are well mixed when they reach the inlet valve. The amount of gas is regulated by the throttle cock *c'*, Fig. 23, which is adjusted to suit the quality of gas used in each individual case.

50. The centrifugal governor in the casing *g'* is operated by gears from the cam-shaft *p*, and controls the amount of mixture admitted according to the load. The governor acts on a throttle *f'*, placed in the admission port between the mixing valve *z* and the inlet valve *m*. After passing through the throttle *f'*, the mixture is subjected to another whirling process by entering the inlet valve *m* through a series of small ports in the body of this valve, before finally being admitted to the combustion chamber.

The flywheel is placed on the crank-shaft extending on the opposite side of the cam-shaft, and the weight of the wheel is supported by an outboard bearing, not shown in the figure. Counterbalance weights are fitted and bolted to the cranks, for the purpose of balancing the reciprocating parts of the engine.

OIL ENGINE WITH VERTICAL FLYBALL GOVERNOR

51. A horizontal four-cycle engine designed to operate on the heavier liquid fuels—such as kerosene, distillates of petroleum, and suitable grades of crude oil—is shown in section in Fig. 25, and the end view of the cylinder in Fig. 26. The construction of the engine bed, base, cylinder, piston, and connecting-rod is of essentially the same character as in similar engines operating on gas or gasoline. The oil-storage tank *a* is placed below the engine inside of the subbase, and the oil is supplied to the cylinder by a plunger pump *b*, Fig. 26, actuated from the cam-shaft by means of



48

Fig. 25

the inlet-valve lever *c* and the cam *d*. A handle *e* attached to the lever *c* serves the purpose of pumping fuel by hand before the engine is in motion.

52. The casing *f*, Fig. 27, contains the inlet and exhaust valves *g* and *h*, and is provided with a removable

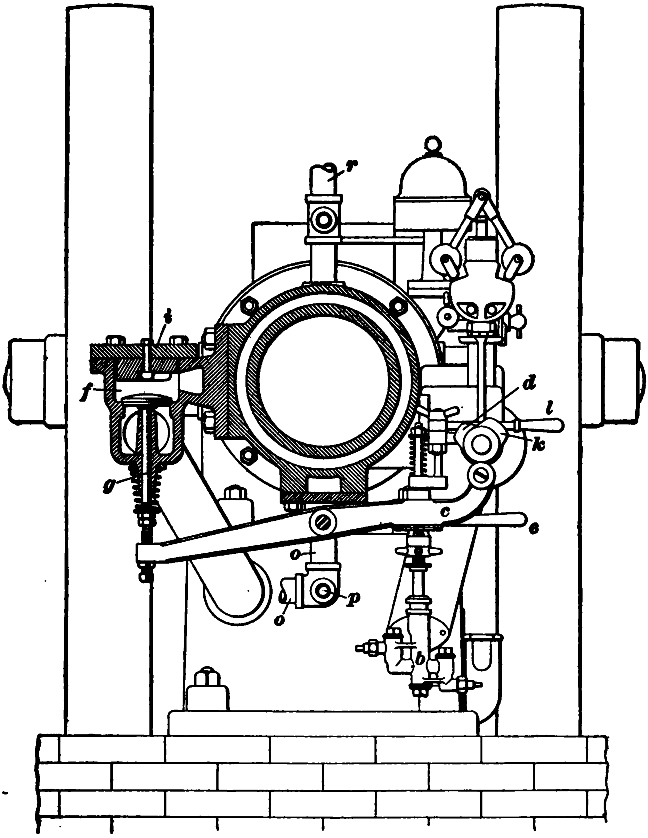


FIG. 26

cover *i*. This casing is attached to the side of the cylinder, as shown at *f*, Fig. 26. The entering charge is admitted to and the products of combustion are expelled from the combustion chamber through a single port *j*, Fig. 25. The

exhaust valve is opened by the cam *k*, Fig. 26, and the cam-sleeve can be shifted horizontally by means of the hand lever *l*, so as to temporarily engage the auxiliary cam that acts on the exhaust valve for the purpose of relieving the compression while starting the engine by hand.

The evaporation of the heavy liquid fuels used in this engine necessitates a specially designed cylinder head, the principal object being to keep the vaporizing chamber *m*, Fig. 25, at a sufficiently high temperature to accomplish this object. As will be seen in Fig. 25, only a small portion of the cylinder head has a water-jacket. As the working cylinder must be cooled to the same degree as in any gas or gasoline engine, it is necessary to provide separate cooling-water supplies for both cylinder and cylinder head. The water connections are shown in Figs. 25 and 26, the pipe *o* being the main supply pipe entering at the bottom of the cylinder, and the pipe *p* being a smaller branch pipe with a regulating valve *q*, to admit a small quantity of water to the cooled portion of the cylinder head. The overflow pipes *r*, *r* carry the hot water to the drain pipe or back to the cooling-water tank.

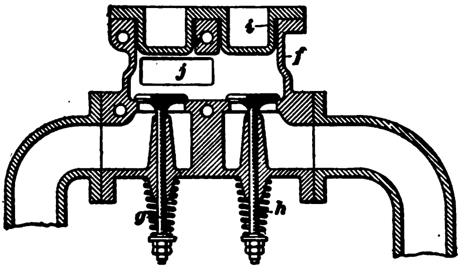


FIG. 27

53. Vaporizer.—The extreme outer end *s* of the vaporizing chamber *m*, Fig. 25, is a separate casting provided with internal ribs *u* and protected from the cooling effect of the air by the removable hood *v*, which, in the case of heavy oils, such as crude petroleum, is filled with asbestos to assist in keeping the heat in the vaporizer. Before starting, the vaporizer is heated by a burner using kerosene or similar fuel. The fuel is sprayed into the combustion chamber on the side nearest the cam-shaft and strikes against the ribs *u*, which are kept at a red heat by the combustion

of the mixture in the chamber. Air enters the cylinder at the port *j*, being taken from the hollow space in the front part of the subbase *w* and conveyed to the inlet-valve chamber through the air pipe *x*. The neck *y* of the vaporizing chamber is reduced in area so as to give the air a greater velocity when forced into the rear portion of the chamber by the

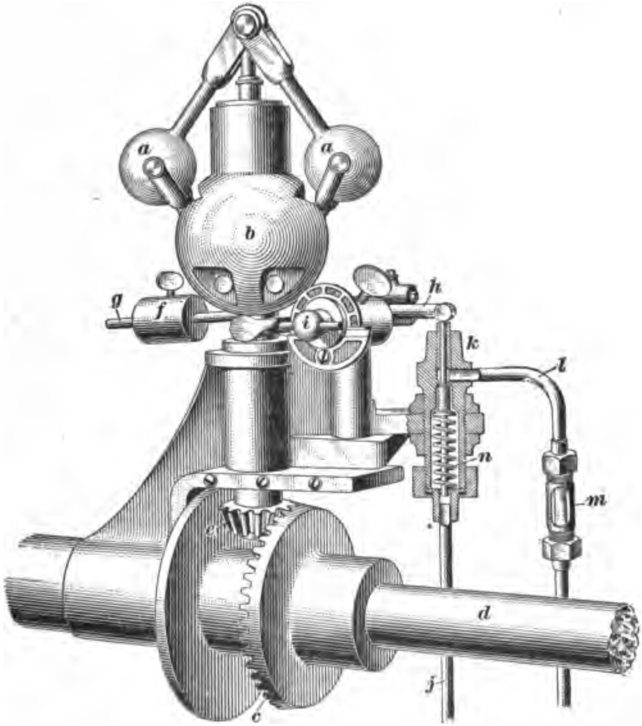


FIG. 28

piston during the compression stroke. This increased velocity of the air-current assists in atomizing the fuel, which is timed so as to enter the chamber at the period of the stroke when the air velocity is greatest.

The temperature required to evaporate the fuel is also sufficient to fire the compressed charge at the proper time—at the end of the compression stroke—thus obviating the use of any separate ignition device. The lighter grades

of fuels, such as distillate and kerosene, require, of course, a lower temperature of the vaporizer to evaporate and fire the charge than the less volatile crude petroleum.

54. Governing Mechanism.—The engine is governed by varying the amount of fuel sprayed into the air-current in accordance with the load. A charge is admitted and exploded at every fourth stroke under all loads, thus tending to keep the vaporizing chamber at a reasonably constant temperature.

The details of the governor and the manner in which it acts on the fuel supply are shown in Fig. 28. The governor is of the centrifugal flyball type, the centrifugal force of the weights *a*, *a* tending to raise or lower the sleeve *b* on the vertical governor shaft. A gear *c*, keyed to the cam-shaft *d*, and meshing with the pinion *e*, transmits the rotary motion of the cam-shaft to the governor. The effect of the governor is partly controlled by the weight *f*, which is mounted on the extension *g* of the governor lever. When the weight *f* is removed, the engine will run at its maximum speed, and the speed can be varied within a certain range by sliding the weight *f* on the extension rod closer to or farther from the governor shaft while the engine is in operation.

55. The governor lever *h* is pivoted at *i*; one end is fork shaped, being attached to the lower part of the governor sleeve *b*, while the other end acts on a by-pass device that regulates the fuel supply. The pipe *j* attached to the bottom of the by-pass is connected to the delivery pipe of the fuel-supply pump. The by-pass contains a compound taper-seat valve *k*, consisting of a small inside and a larger concentric outside valve that can be regulated by the action of the governor lever *h*. If the speed of the engine exceeds the normal, the governor sleeve *b* is raised and the free end of the governor lever is lowered, opening the inner poppet of the overflow valve *k*, and allowing part of the fuel supplied by the pump to return to the tank by means of the overflow *l*. The sight glass *m* is provided for the purpose of enabling the operator to watch the action of the pump and by-pass device. While running under full

load, the spring *n* practically closes the overflow valve and the greater amount of oil supplied by the pump is sprayed into the vaporizing chamber. When running idle, both the outer and inner valves are opened, and only the minimum amount of fuel necessary to produce a weak combustible mixture is admitted to the vaporizing chamber.

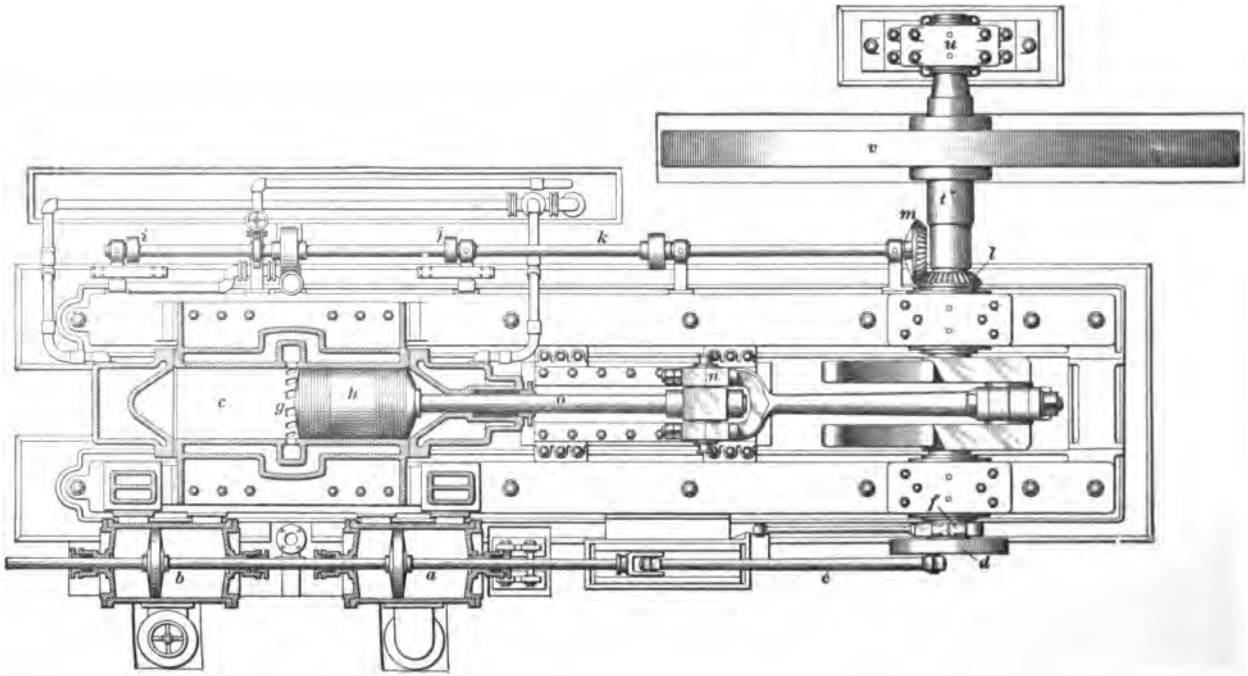


FIG. 1

series of ports g in the cylinder wall uncovered at the end of the expansion stroke by the movement of the piston h.

2. Air and Gas Pumps.—The air and the gas are supplied by separate cylinders, the pump a supplying the air, and the pump b the gas. The pumps are placed tandem, both pistons being fastened to the same rod. The arrangement of the passages through which the charging pumps

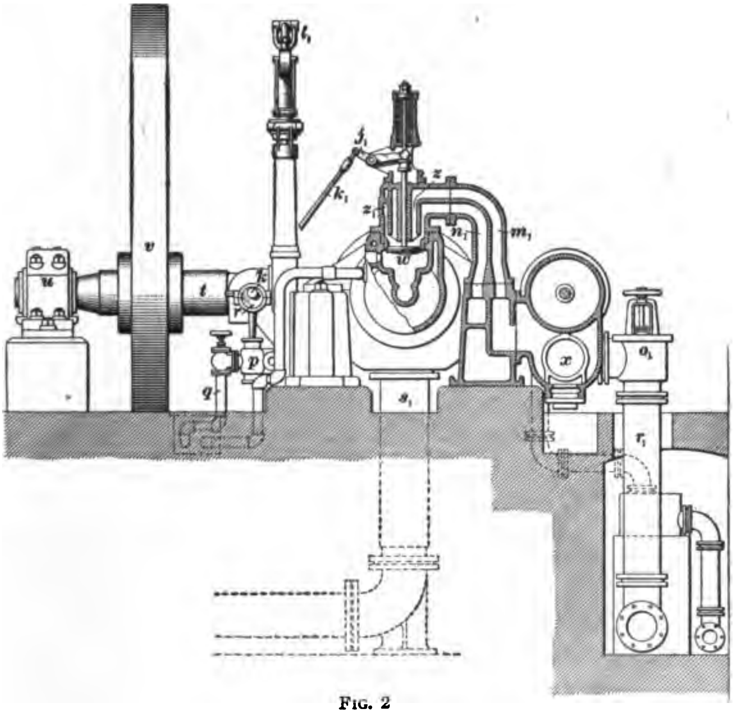


FIG. 2

deliver gas and air to the two ends of the main cylinder is shown diagrammatically in Fig. 3, in which a is the air pump and b the gas pump. Each end of each pump discharges into a separate duct, the gas and the air from the crank ends of the pump cylinders passing to the crank end of the main cylinder through the passages p_1 and q_1, and from the head ends of the pump cylinders to the head end of the main cylinder through the ducts m_1 and n_1. The admission of

air and gas is timed by the piston valves x and y. The air and gas are mixed while passing through the inlet valves w and w_1.

3. **Inlet Valves.**—The arrangement of the inlet valves is shown in the end view, Fig. 2. The valves are of the vertical-poppet type, and the gas and air passages end in annular openings z and z_1 concentric with the inlet valves w and w_1, Fig. 3, the inside passage admitting the gas and the outside passage the air. The piston valve x of the gas pump b is timed so that a charge of pure air only is admitted to the engine cylinder during the first part of the stroke, resulting in a scavenging of the main cylinder and placing a separate layer of air between the burned and the fresh charges. While the air cylinder of the pump a discharges during its entire stroke, no gas is delivered until a certain point of the gas-pump stroke has been reached. Suppose that the right-hand end of the engine cylinder is to be charged. The charge of pure air strikes the closed inlet valve w_1 and is pushed back through the gas passage p_1, forcing the gas before it. The result is that, as soon as the inlet valve w_1 opens, both passages p_1 and q_1 at first discharge air only; later, q_1 discharges air, and p_1 gas. Thus, the air that enters the cylinder first forms the scavenging charge—that is, the charge that keeps the burned gases out of the cylinder—while the following mixture of gas and air forms the combustible charge. The gas-supply pipe r_1, Fig. 2, is fitted with a hand-operated throttle valve o_1, by means of which the fuel is turned on or shut off.

The inlet valve at each end of the working cylinder is actuated by cams, shown at i and j, Fig. 1, on the main-valve gear-shaft k, by means of a lever j_1 and a push rod k_1, Fig. 2. The valve gear-shaft is driven by miter gears l and m from the main crank-shaft t, as shown in Fig. 1.

4. **Admission of the Charge.**—The timing of the main and pump pistons is so arranged that, when the main piston shown at h, Fig. 3, begins to uncover the ports g, the charging-pump piston of the gas cylinder b has reached about the

the inlet-valve lever *c* and the cam *d*. A handle *e* attached to the lever *c* serves the purpose of pumping fuel by hand before the engine is in motion.

52. The casing *f*, Fig. 27, contains the inlet and exhaust valves *g* and *h*, and is provided with a removable

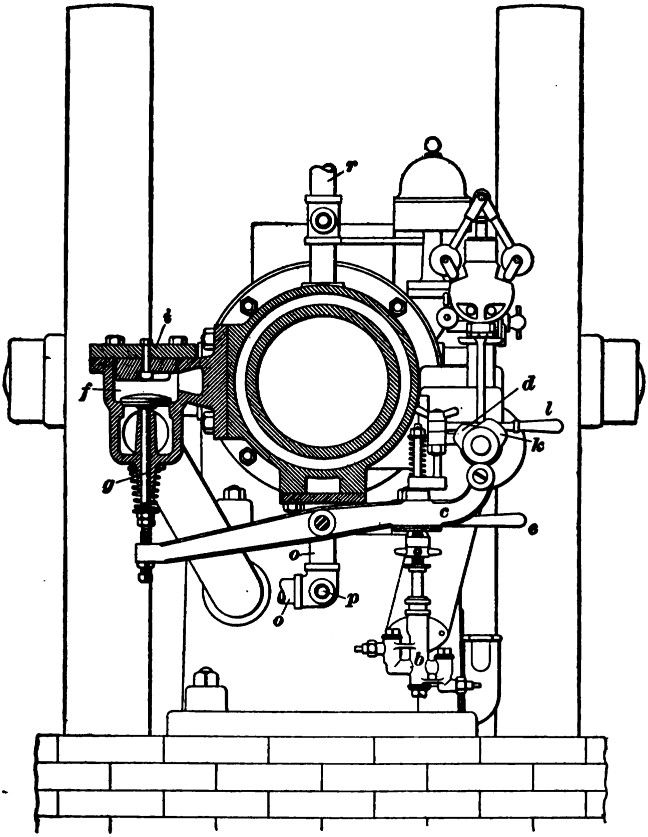
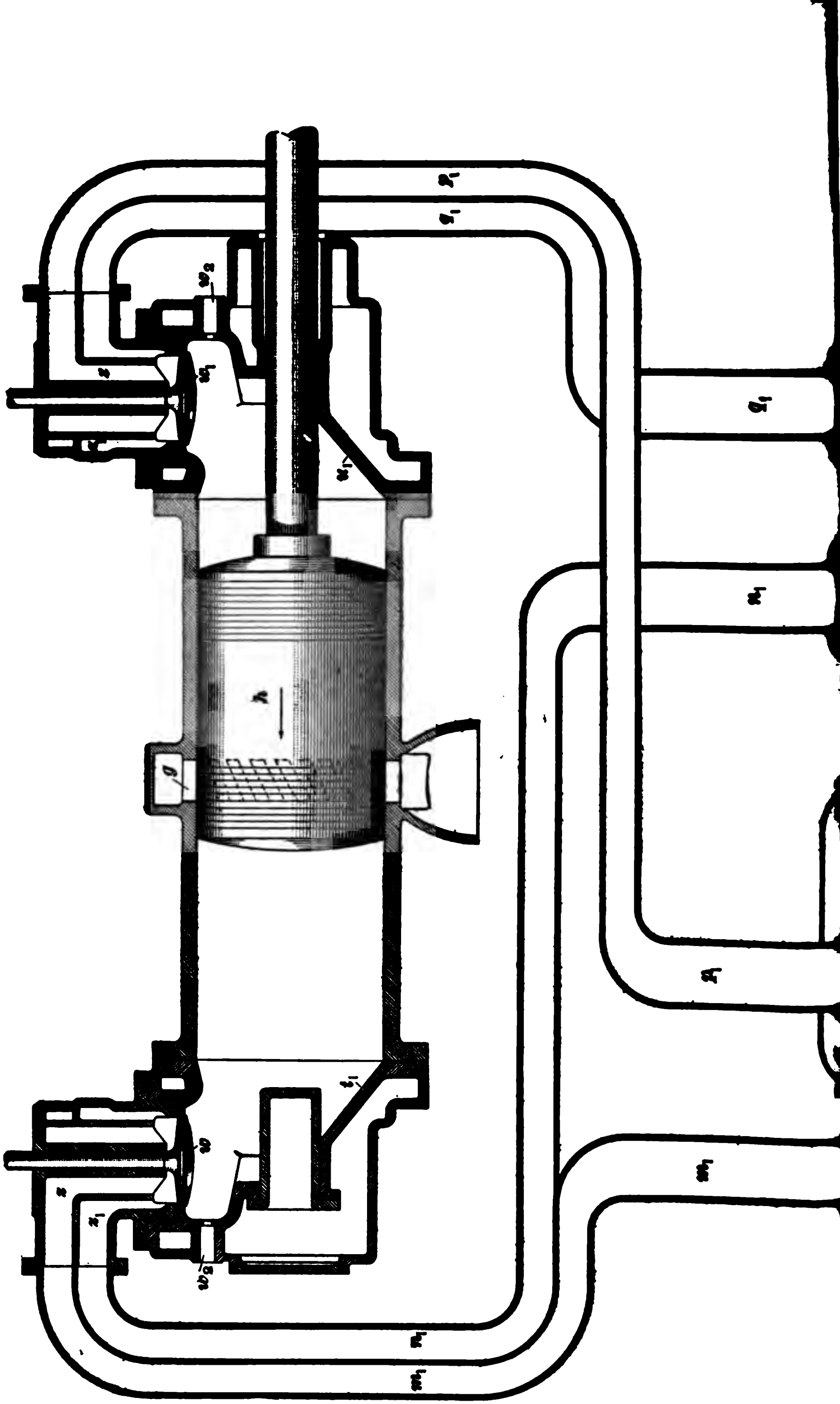


FIG. 26

cover *i*. This casing is attached to the side of the cylinder, as shown at *f*, Fig. 26. The entering charge is admitted to and the products of combustion are expelled from the combustion chamber through a single port *j*, Fig. 25. The



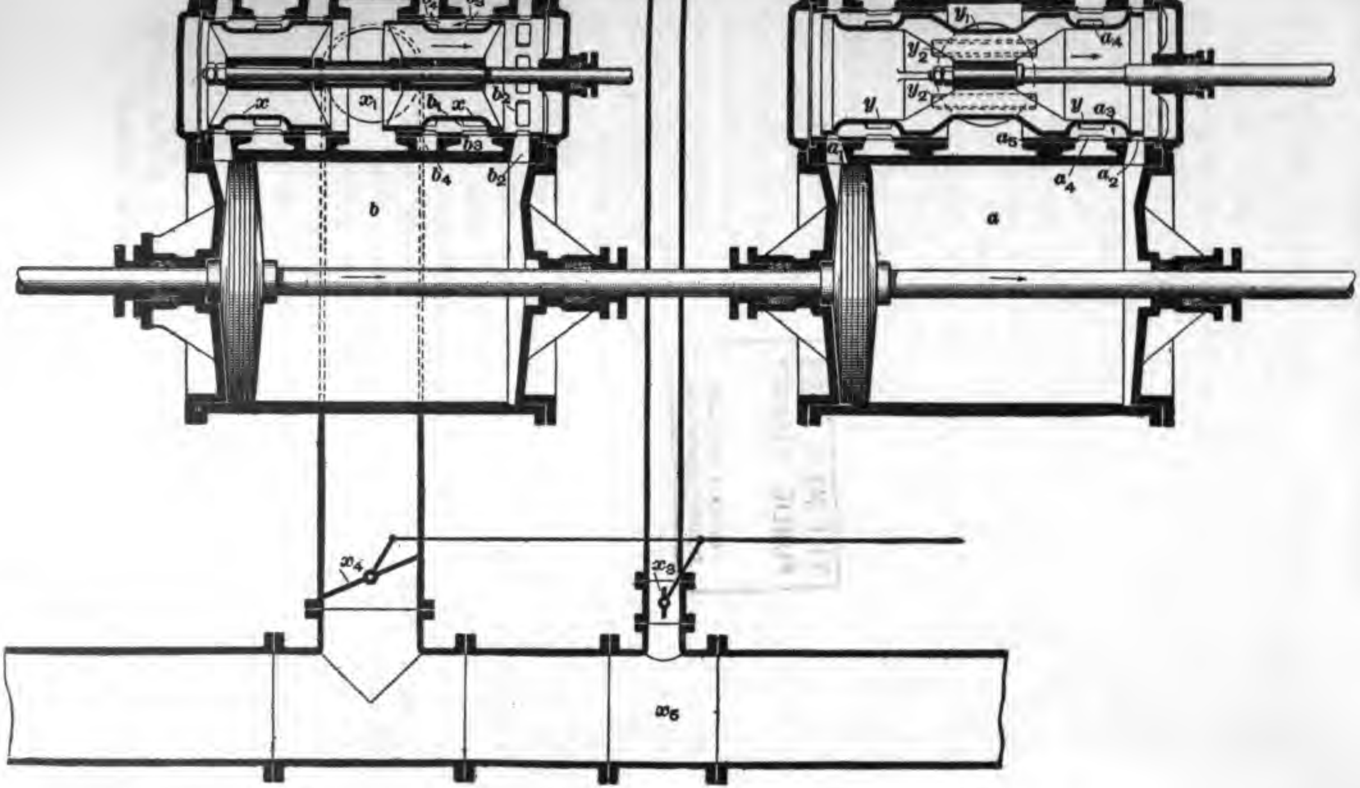


FIG. 3

middle of its discharge stroke. In the position shown in Fig. 3, the piston h is moving in the direction indicated by the arrow, under the power impulse due to the expansion of the charge that has just been ignited in the right-hand end of the cylinder; while the charge that has been admitted to the left-hand end of the cylinder is being compressed. The piston valve y of the air pump a is moving toward the right, and is just about to uncover the port a_1 leading to the suction side of the piston, the air flowing from the air-supply pipe y_1 through openings y_2 leading to the central passage in the piston valve. At the same time that the port a_1 is uncovered, the port a_2 is also uncovered, permitting air to flow from the cylinder a through the port a_2 into the annular passage a_3 around the outside of the piston valve, thence through the ports a_4 in the sleeve a_5, in which the piston valve moves, and into the pipe q_1.

While the piston valve y and the piston in the cylinder a are moving in the direction indicated by the arrows, the piston valve x and the piston in the gas cylinder b are also moving in the same direction. When the valve x has moved to the right so that the annular passage b_1 connects the ports b_2 and b_3, the gas passes from the cylinder b into the pipe p_1. On the return stroke of the valve x, the port b_2 is closed to the port b_3, and communication is established with the suction pipe x_1 through the internal passage of the valve x. At the same time, communication is established between the ports b_3 and b_4 by means of the annular passage b_1, thus connecting the pipe p_1 with a by-pass pipe x_2 leading to the gas-supply main x_5. In the by-pass pipe x_2, there is a valve x_3 actuated by the governor, while another valve x_4 similarly controlled is located in the gas-supply pipe x_1. This arrangement permits some of the gas discharged from the gas pump to pass back into the gas main and the charge taken into the other end of the cylinder to be throttled. The amount of gas that returns to the main and the extent to which the new charge is throttled depend on the action of the governor, the operation of which, in turn, depends on the load on the engine.

When the gas from the gas pump b enters the pipe p_1, it encounters a charge of compressed air that has been forced up through the pipe q_1, the annular passages z_1 and z, and back into the pipe p_1, so that, when the inlet valve w_1 opens, as it does when the piston h uncovers the ports g, the products of combustion are swept out of the cylinder by the scavenging charge of air that precedes the charge of gas. When the air in the passage z has been swept into the cylinder, the gas, which follows, mixes with the air from the passage z_1, forming the combustible charge. When the charging operation is complete, the main piston h having again covered the ports g, the inlet valve w_1 closes, compression takes place, and at the end of the compression stroke ignition occurs. The ignition devices are inserted through the openings w_2.

5. **Exhaust.**—The piston h, the length of which is about seven-eighths the length of the stroke, is water-cooled, and performs the functions of an exhaust valve by covering and uncovering at the end of the expansion strokes a series of exhaust ports g in the cylinder wall. After leaving the cylinder, the exhaust gases are carried into the atmosphere through the pipe s_1, Fig. 2. The walls of the main cylinder, cylinder heads, exhaust ports, and stuffingboxes are cooled by water circulation. The water that cools the piston h, Fig. 1, enters through the hollow crosshead pin n, and is discharged through a pipe placed inside of the hollow piston rod o.

6. **Distribution of the Charge.**—The governor l_1, Fig. 2, is of the centrifugal flyball type, driven by spiral gears from the cam-shaft k, and acts through a series of levers and links on the butterfly valves x_3 and x_4, Fig. 3, opening and closing them according to the load, thus controlling the amount of gas admitted and keeping it always proportionate to the load on the engine. Under a light load, the charge of combustible mixture is decreased in volume, while the proportion of scavenging air is correspondingly increased, thus maintaining the same degree of compression

as under full load. The design of the baffle surfaces t_1 and u_1 of the combustion space, Fig. 3, is such that the air first admitted spreads over the entire area of the cylinder and is pushed forwards by the combustible mixture that follows. While the two portions of the charge are mixed to a certain degree during the compression stroke, the richer mixture remains at the rear of the combustion chamber, near the igniters. The flywheel *v*, Fig. 2, is placed on an extension of the main shaft *t*, supported by the outboard bearing *u*.

7. Starting the Engine.—The starting of the engine is accomplished by compressed air stored in a tank of suitable capacity at a pressure of from 100 to 150 pounds per square inch. A piston valve *p*, Fig. 2, admits this air through the pipe *q* alternately to each end of the working cylinder, the inlet valve being operated by an eccentric *r* on the cam-shaft *k*. The compressed-air admission valve *p* can be thrown in gear or disconnected from the cam-shaft *k* by means of a hand-operated friction clutch.

SINGLE-CYLINDER VALVELESS ENGINE

8. Arrangement of Pistons.—A two-cycle gas engine in which the fuel and air are admitted and the exhaust gases expelled without employing valves is diagrammatically illustrated in Fig. 4. The characteristic features in this design involve the use of two long pistons open at the outer ends, known as **trunk pistons**, reciprocating in a single cylinder *a*; the one piston *b* is connected to the center crank *c* of a triple crank-shaft, while the other piston *d* is attached by the yoke *e* and the rods *f*, *f* to the two side cranks *g*, *g* through the crossheads *o*, *o*. It will be seen that, during the explosion and expansion stroke, the two pistons move in opposite directions, thus causing the forces on the crank-shaft to act in opposite directions and resulting in a perfect balancing of the reciprocating parts and forces acting on the crank-shaft and main bearings. Furthermore, the combustion chamber formed by the cylinder and the pistons when they reach their inner positions is extremely simple in form, having no pockets

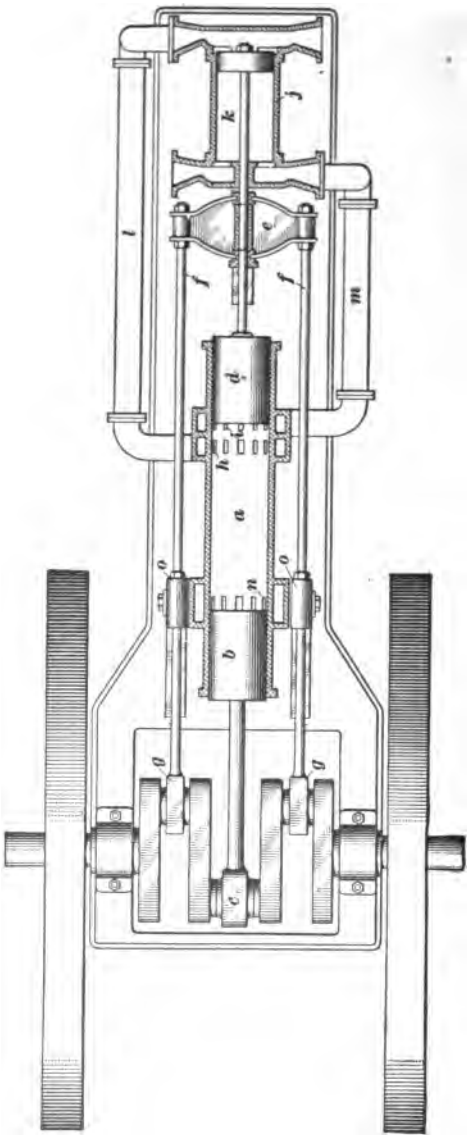
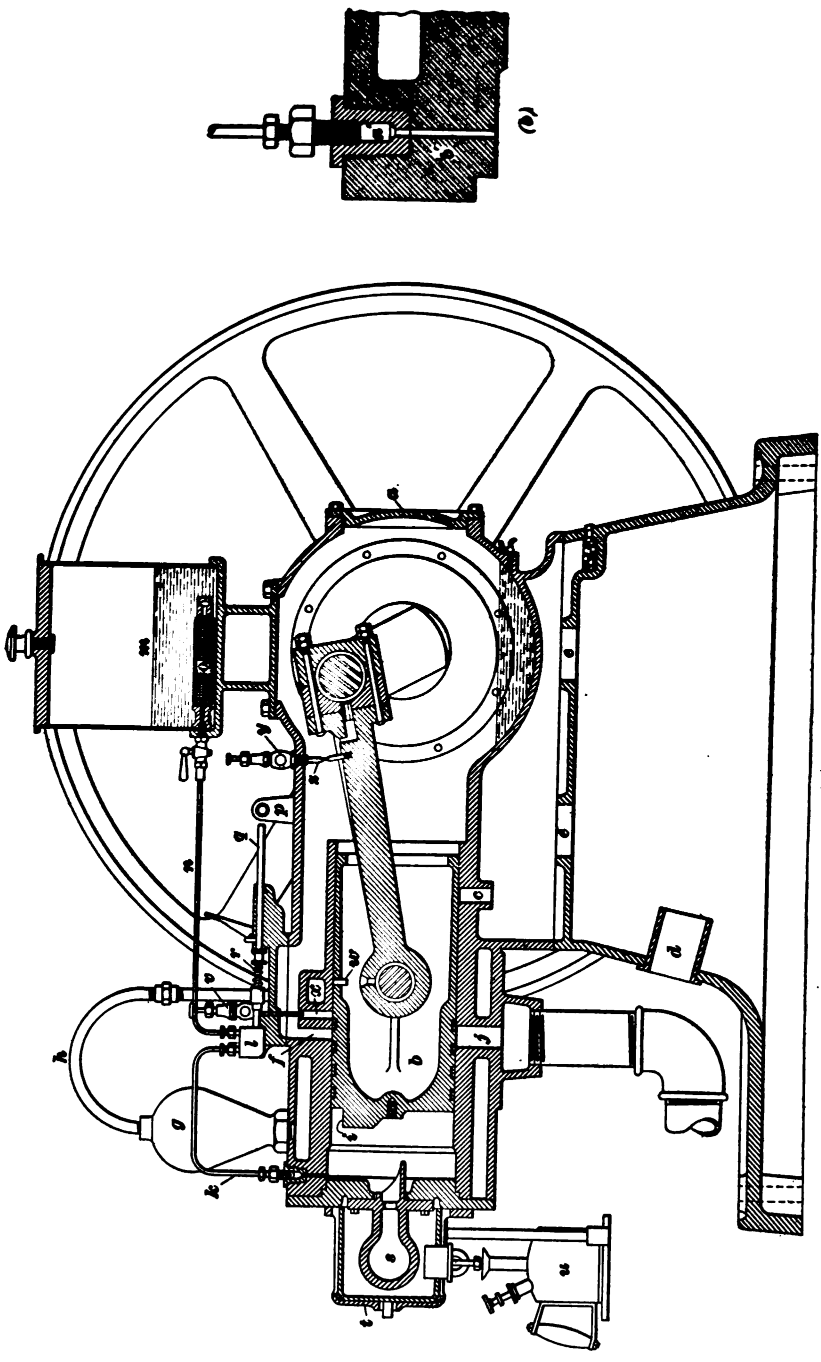


FIG. 4

and only a minimum amount of surface exposed to the cooling water, and giving a high thermal efficiency to the engine.

9. Admission and Exhaust.—The charge is admitted through the air ports *h* and the gas ports *i* when uncovered by the piston *d*. The pump *j*, of the double-acting type, furnishes the charge at a pressure of about 6 pounds per square inch. The piston of the charging pump is driven by the extension *k* of the piston *d*. The air is supplied by one end of the pump through the pipe *l*, and the gas by the other end of the pump through the pipe *m*. The pump valves are not shown. Previous to the opening of the admission port, the piston *b* has uncovered the exhaust ports *n*, allowing the products of combustion to escape by way of the exhaust pipe. This clearing of the cylinder is hastened by the entering charge of air under pressure, as already explained, and it is only after the air has thus scavenged the combustion chamber that the gas ports *i*, in the rear of the air ports *h*, are opened by the further movement of the piston *d*. The gas now mixes with the air, and the charge is compressed by the inward movement of the two pistons, after the exhaust and admission ports have been closed by the pistons. Ignition takes place when the cranks have reached their dead centers, and the cycle of operations is repeated, as previously described.

10. Governing.—The governor controls the quantity of combustible mixture admitted according to the load on the engine. If this were accomplished by the cut-off method, it would create a vacuum detrimental to the efficient working of the engine. To avoid this, the entire charge is admitted at all times, under light and heavy loads, and the governor controls a return valve—the only valve on the engine—which is located on top of the cylinder and permits a portion of the charge to be returned to the supply pipe and kept ready for use during the next cycle. The opening of this return valve and the amount of mixture thus discharged during the first part of the compression stroke vary according to the fluctuations in the load.



(a) (b)

FIG. 5

SINGLE-ACTING OIL ENGINE

11. General Characteristics.—A two-cycle engine of the horizontal type, for heavy liquid fuels, such as kerosene, distillates, and fuel oil, is shown in Fig. 5. This engine ignites the charge automatically by compression in a heated extension of the combustion chamber. While running, this chamber is kept hot by the combustion of the explosive mixture, and before starting, it is heated by a kerosene burner or torch furnished with the engine. The general design and method of operation of the engine is illustrated in the longitudinal section, Fig. 5 (*a*).

12. Air Supply.—The crank-case *a* is closed and forms an air chamber in which the pressure varies according to the movement of the piston *b*. A partial vacuum is created in the crank-case during each inward stroke of the piston, and at the end of this stroke the piston uncovers the port *c* in the lower cylinder wall, and the air rushes into the closed crank-case, where it is compressed during each forward stroke of the piston. The air is drawn from the atmosphere into the base of the engine through a short tube *d* and up through the ports *e*, *e*, in the top of the base, to the port *c*. Toward the end of the outward stroke, the piston uncovers a port *f* in the upper wall of the cylinder, through which the compressed air is forced into the combustion chamber. To the air is added a quantity of steam generated by the heat of the combustion acting on the cooling water in the cylinder jacket, the water supply being regulated so as to keep the temperature of the water slightly above the boiling point. The steam passes from the jacket into the vessel *g*, and thence through the pipe *h* into the cylinder, air and steam being guided toward the head of the combustion chamber by the deflector *i*. Simultaneously, the piston at the end of the forward stroke uncovers the exhaust port *j* in the lower cylinder wall, and permits the exhaust gases to escape.

13. The Oil Pump.—The oil for the charge is injected into the combustion chamber through the pipe *k*, Fig. 5 (*a*),

by a small pump *l*, the fuel being supplied to the pump by gravity from the oil vessel *m* placed on top of the crank-case. The supply pipe *n* is provided with a stop-cock, and at the end of the pipe in the tank is a felt or gauze strainer *o*.

The introduction of the oil into the combustion chamber and the regulation of the quantity of fuel as desired is accomplished in the following manner: The lever arm *p*, a detail of which is more clearly shown at *p*, Fig. 6, is connected to an eccentric on the crank-shaft and acts on the

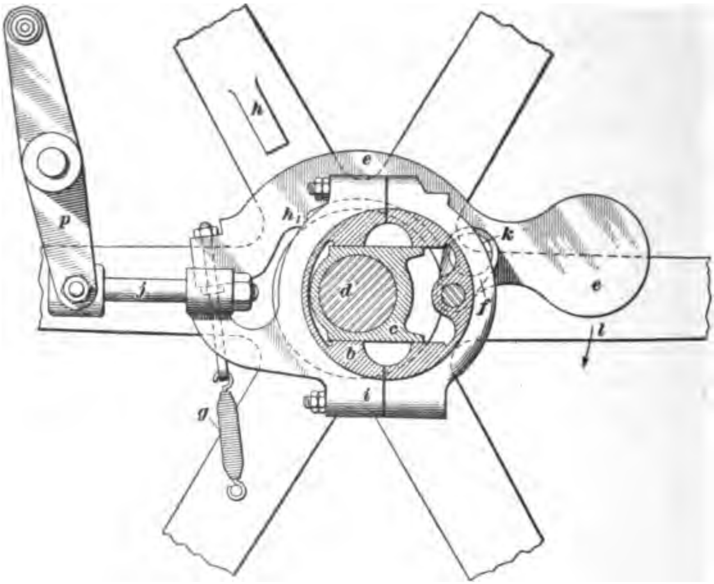


Fig. 6

plunger rod *q* of the oil pump, moving the rod horizontally against the tension of the spring *r*. The oil being discharged from the pump cylinder through the pipe *k* enters the small auxiliary chamber shown at *a'*, Fig. 5 (*b*), communicating with the combustion chamber through a small port *b'*.

14. Injection of the Fuel.—During the compression stroke, the air in the chamber *a'*, Fig. 5 (*b*), is under pressure, and prevents the oil from entering the cylinder. As

soon as the piston has started on its outward stroke, the pressure in the cylinder is slightly reduced, and the air contained in the chamber *a'* expands and rushes into the combustion chamber through the small opening *b'*. At this instant, the oil is injected into the chamber *a'*, and is carried into the compressed charge of air, the mixture being ignited in the heated chamber *s*, Fig. 5 (*a*), which communicates with the cylinder by means of a contracted port. The resulting expansion drives the piston *b* outwards, and power is transmitted to the crank-shaft through the connecting-rod in the usual way, during the remainder of the outward stroke of the piston. A check-valve fitted to the oil-feed pipe *k*, has a poppet valve and coil spring, the tension of which is regulated so that the valve closes only during the expansion. While combustion and expansion are taking place in the cylinder, a new charge of air, admitted during the return stroke of the piston, is compressed in the crank-case, and the cycle of operations is repeated.

15. Ignition Chamber.—The igniting chamber *s*, Fig. 5 (*a*), is protected against cooling by being surrounded with a removable hood, or casing, *t*. To further aid in retaining the heat, which may be desirable when using very heavy grades of oil, the space surrounding the igniting chamber may be filled with asbestos or similar non-conducting material. After standing idle for any length of time, the igniting chamber cools off, and in order to be able to start the engine the chamber must be heated by external means. For this purpose, a kerosene burner or torch *u* is provided to heat the chamber *s* to the required temperature.

16. Governing the Engine.—The eccentric for operating the oil pump and the governor is shown in detail in Fig. 6. The eccentric *b* is supported on a guide *c*, which is fastened to the end of the crank-shaft *d*. The eccentric *b* is free to move on the guide *c*, the movement being controlled by the governor. The governor consists of the weight arm *e* connected to the eccentric by means of the link *f*, the spring *g*, and the stops *h* and h_1. The eccentric is connected to the

lever *p* by means of the strap *i* and the connecting-rod *j*. If the speed of the engine exceeds the normal number of revolutions per minute, centrifugal force causes the governor weight arm *e*, pivoted to the flywheel at *k*, to move about *k* in the direction of the arrow *l*, thereby shifting the eccentric by means of the arm *f* toward the center of the crank-shaft and decreasing the eccentric radius, or eccentricity, and consequently the reciprocating movement of the lever *p*. The upper arm of the lever *p* operates the oil pump, and the stroke of the pump plunger is thus regulated by the governor. As soon as the speed shows a tendency to fall below the

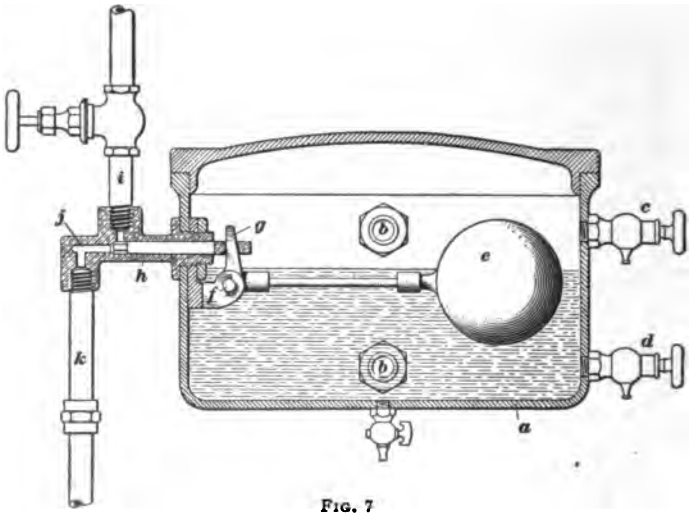


FIG. 7

normal, the governor weight reverses its movement, the amount of the eccentricity and the stroke of the pump are increased, and a correspondingly greater amount of fuel is admitted to the cylinder. From what has been stated, it will be seen that a small quantity of oil, always proportionate to the load on the engine, is admitted at every revolution. The speed of the engine may be varied by adjusting the tension of the governor spring *g*.

17. Cooling the Cylinder.—The water for cooling the cylinder and generating the steam that is added to the air is

taken either from a supply pipe or from a tank. The amount of water admitted is regulated, before entering the cylinder jacket, by a float box and its connections, shown in Fig. 7. The box *a* is held in position by the pipe and fittings *b*, *b*, connecting the box to the cylinder jacket, and is equipped with two gauge-cocks, the upper cock *c* showing steam and the lower cock *d* water. The water is kept at a constant level, at about the top of the water-jacket, by the action of the ball float *e* pivoted at *f*. Whenever the level of the water falls below the desired point, the float acting on the lever *g*

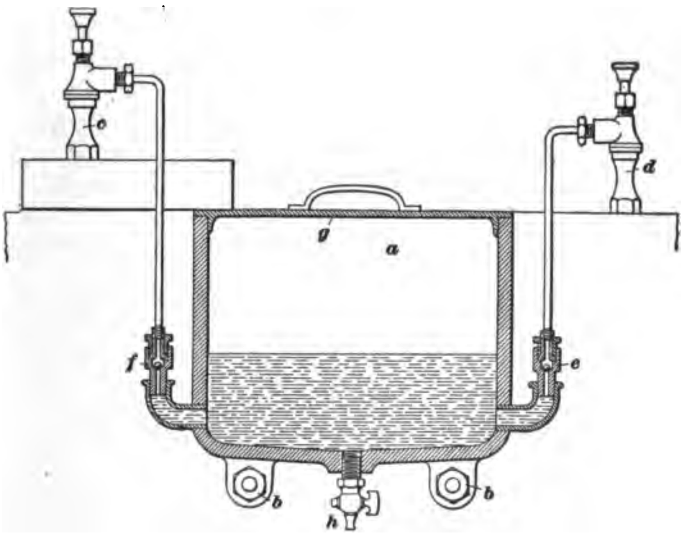


FIG. 8

withdraws the valve *h* from its seat and thereby opens communication between the water-supply pipe *i* and the port *j* leading to the pipe *k*, which conveys the water to the cylinder jacket. The interior of the box being in communication with the water space in the cylinder jacket, it will be seen that, as soon as the level of the water in the jacket falls below the point fixed by the float, fresh water is automatically admitted, until the float in rising shuts off the supply by closing the valve *h*.

18. Lubrication.—The main journals of the crank-shaft are fitted with ring oilers of the usual type, revolving with the shaft and carrying oil up from a reservoir in the bottom of the bearing box, the oil well being filled through a funnel-shaped opening in the bearing cap. Any oil that runs out of the bearings is caught in collars fitted to the outer end of the brass liner, and is returned to the oil well. A specially designed oil vessel with attachments for supplying lubrication to the crankpin and piston pin is illustrated in the sectional view, Fig. 8, the oil cups *c* and *d* being indicated at *v* and *y*, Fig. 5 (*a*).

19. The oil reservoir *a*, Fig. 8, is attached to the side of the cylinder by means of lugs and studs *b*, *b*. The level at which the oil stands relative to the oil cups *c* and *d* requires a certain amount of vacuum supplied by the engine piston to lift the oil from the vessel to these cups. The cup *c*, shown also at *v*, Fig. 5 (*a*), furnishes oil to the piston pin through the walls of the cylinder. When the piston reaches its innermost position, a tube *w*, Fig. 5 (*a*), attached to the piston registers with the port *x*, and oil flows from the cup to the piston pin. The cup *v* serves also to oil the piston itself, although additional lubrication is effected by the crank dipping into the oil accumulating in the bottom of the crank-case. The oil cup *d*, Fig. 8, shown also at *y*, Fig. 5 (*a*), has a tube *z*, Fig. 5 (*a*), projecting from its lower end into the crank-case. This tube is brought into contact with a wiper attached to the connecting-rod at every revolution of the crank-shaft. The oil suspended at the end of the tube *z* is thus conveyed to the crankpin through a port drilled into the connecting-rod end. As will be seen in Fig. 8, ball check-valves are provided at *e* and *f*, through which the oil passes from the vessel *a* to the oil cups. These valves prevent the pressures in the cylinder and crank-case from forcing the oil back into the oil tank. The contents of the oil vessel can be inspected and replenished through the opening in the top covered by the removable cover *g*, while the drain cock *h* serves to remove any sediment or impurities that may gather in the bottom of the vessel.

VERTICAL GAS ENGINES

FOUR-CYCLE TYPE

SINGLE-ACTING GAS AND GASOLINE ENGINES

20. The Cylinder.—A large type of vertical four-cycle engine governed by the hit-or-miss method is illustrated in Figs. 9 to 12, inclusive. Fig. 9 shows a sectional view through the cylinder and the valve chamber. A sectional view of the valves and mixing chamber as used on the same engines when running on liquid fuel, looking from the other side of the engine, is shown in Fig. 10, and a view of the gasoline feeding device is illustrated in Fig. 11.

21. Referring to Fig. 9, the base *a* supporting the pillow-blocks *b*, which form the main bearings for the crank-shaft journals, is fastened to the base plate *c* bolted to the top of a brick or concrete foundation. The cylinder *d* is supported by the frame, or housing, *e*, which is provided with removable doors to give access to the main bearings and crankpin boxes. The chamber containing the air and gas inlet and exhaust valves is cast in one piece with the cylinder, the whole casting being open at the top and closed by the water-cooled cylinder head *f*. The cooling-water supply enters the lower part of the cylinder jacket at *g*, while the outlet *h* at the top of the cylinder head carries off the water to the drain pipe.

22. The Valve Gear.—The shafts carrying the cams that operate the igniter and valves are driven by spur gears located inside the frame. The pinion on the crank-shaft meshes with a gear having twice as many teeth as the pinion and mounted on the valve cam-shaft *l*. From this shaft,

the motion is transmitted to the ignited eccentric shaft *j* by means of bevel gears and an auxiliary shaft.

The air and gas inlet valves are of the vertical-poppet type. The air valve *k* is lifted by the cam on the shaft *l*, which strikes the roller *m* on the lever *n* pivoted at *o*. A coil

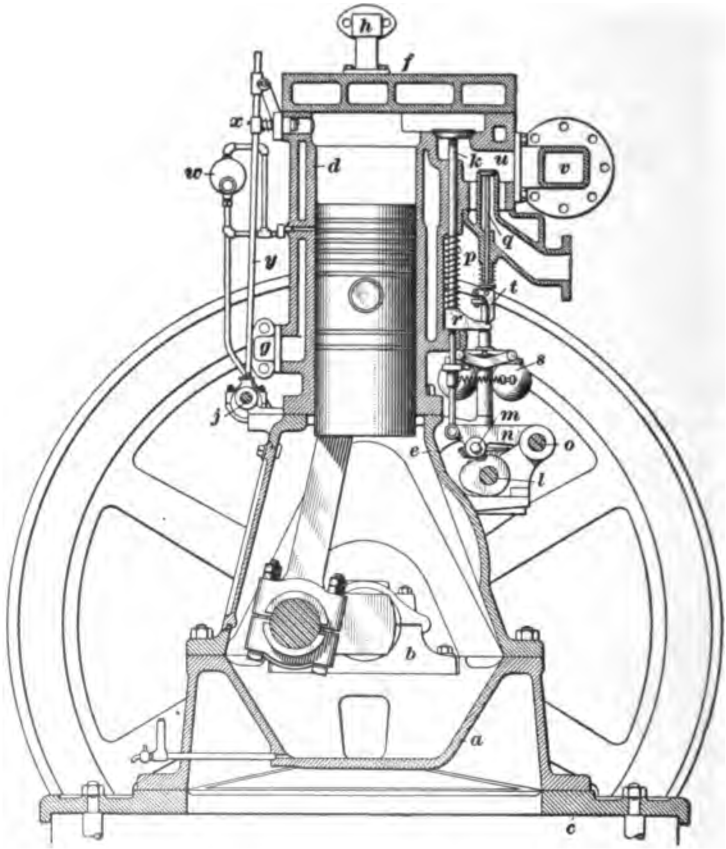


FIG. 9

spring *p* forces the valve on its seat after the cam has passed the roller attached to the lever *n*. The gas valve *q* is opened by the arm *r*, which is attached to the stem of the air-inlet valve, provided the centrifugal ball governor *s* permits a swinging blade *t* pivoted on the end of the gas-valve stem

to engage with a correspondingly shaped catch on the arm *r*. The governor controls the blade *t*, so that, when the speed of the engine exceeds the normal, the blade is moved out of the path of the arm, and, no gas being admitted, the engine takes a charge of pure air only.

The exhaust valve is located directly behind the inlet valve, and is therefore not visible in Fig. 9. The exhaust gases, as soon as the exhaust valve is opened by a cam and lever similar to the air-valve cam *l* and lever *n*, pass through a port back of the inlet port *u* into the exhaust pipe *v* attached to the side of the cylinder.

23. Lubrication and Ignition.—The main bearings and the crankpin bearings are lubricated by the splash system, the lubricant being contained in the bottom of the base *a*; while the cylinder and piston, as well as the bearings of the cam-shafts, are lubricated from the oil reservoir *w*, individual pipes from adjustable oil cups leading to the points to be lubricated.

The electric igniter plug *x* is inserted into the combustion chamber immediately below the cylinder head, and the igniter is actuated by the rod *y* from an eccentric placed on the shaft *j*.

24. Gasoline Attachments.—An enlarged sectional view of the mixing chamber, as designed for the use of gasoline in the engine just described, is shown in Fig. 10; while Fig. 11 represents a view of the gasoline feeding device. The air supply is so regulated that a portion enters through the passage *a*, Fig. 10, while a sufficient amount to vaporize the fuel is admitted through the opening *b*. The fuel is supplied by a pump, operated from the cam-shaft, to a small tank *c*, in which a constant level is maintained by the overflow pipe *d*. From the reservoir, the fuel flows to a small orifice, the opening of which is regulated by the needle valve *e*.

The highest point of the nozzle *f*, through which the fuel is sprayed into the mixing chamber, is slightly above the level of the gasoline in the reservoir *c*. The air-current,

passing the nozzle *f* with considerable velocity, creates a suction at this point sufficient to draw a certain amount of gasoline into the mixing chamber. After passing through several layers of fine-wire gauze *g*, the air and atomized fuel are admitted through the gasoline valve *h* into the port *a*,

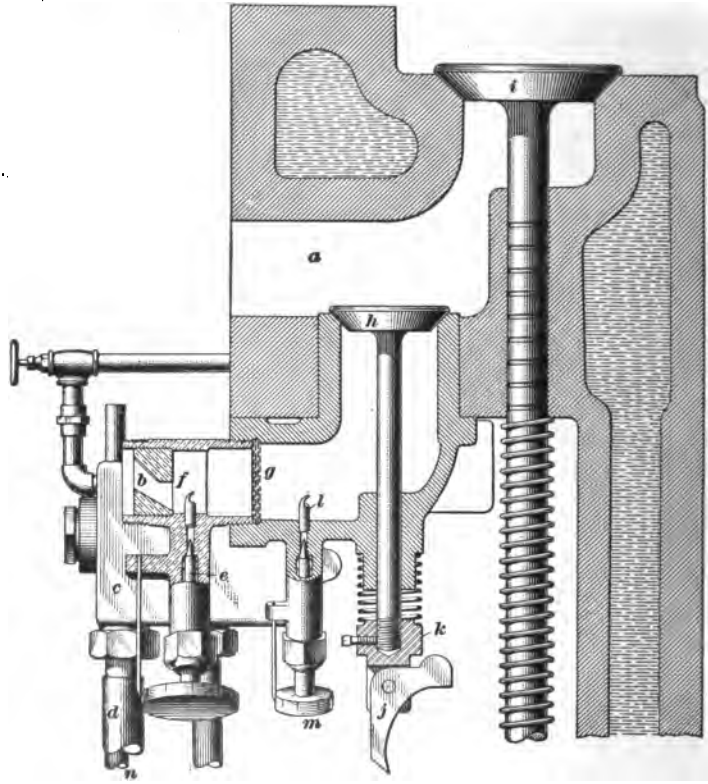


Fig. 10

whence they pass into the combustion chamber in the form of an explosive mixture through the main inlet valve *i*.

25. Speed Regulation With Gasoline as Fuel.—The opening of the gasoline valve *h* is controlled by the governor in the same manner as when using gas. The blade *j*, pivoted on the valve nut *k*, is moved by the governor so that it engages with the arm *r*, Fig. 9, whenever the speed is

normal. Under light loads, the governor moves the blade *j* out of the path of the arm *r*, the valve *h* remains closed, and the engine receives pure air only.

When working under heavy load, the engine is naturally liable to heat up more than under light load. To avoid premature ignition under these conditions, provision is made to add a small quantity of water to the mixture of air and gasoline, which has the effect of cooling the combustion chamber. This water supply is admitted to the mixing chamber through the nozzle *l*, Fig. 10, regulated by the needle valve *m*. The gasoline vapor passes through the wire-gauze screen *g* before it meets the spray of water.

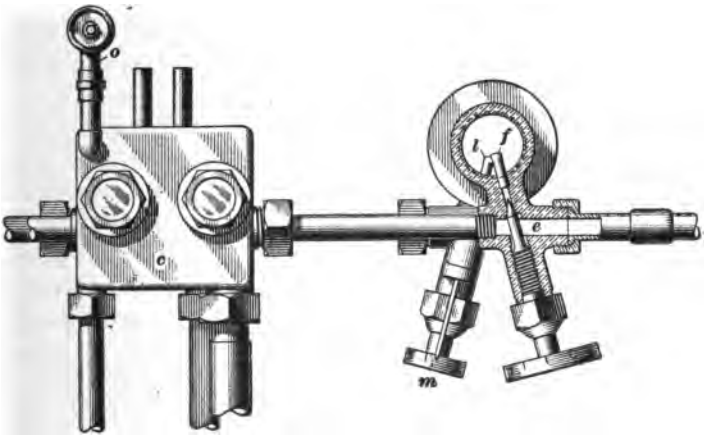


FIG. 11

The reservoir *c* is divided by a partition into two chambers—one for gasoline and one for water. The water is admitted through the supply pipe *o*, Fig. 11, which shows another view of the tank *c* and the valves *e* and *m*, while the excess water is carried off by the overflow pipe *n*, Fig. 10, the amount in the reservoir being regulated by the height of the overflow pipe that projects into the reservoir.

26. Throttling Governor for Gas Fuel.—A mixing valve and governor connections for an engine of this type arranged for throttling a mixture of air and gas to correspond

to the conditions of the load are shown in Fig. 12. The mixing-valve casing *a* is provided with flanges *b* and *c* for connecting the air and gas supply pipes. The opening of the gas valve *d* is regulated by the adjusting screw and locknut at *e*. The air-inlet valve consists of a sleeve *f* provided with ports opening into the mixing chamber, the sleeve being mounted on the threaded portion of the valve stem *d*. After passing through the mixing valve, the mixture of gas and air enters the inlet-valve chamber *g* through throttling valve *h*, controlled by the governor and consisting of an outer sleeve *i* and a piston valve *j*, both having a series of ports that so register as to have a full opening when the load is heavy and a small opening when the load is light. The volume of the charge having been regulated by the throttling valve, the mixture passes through the inlet valve *k* into the engine cylinder.

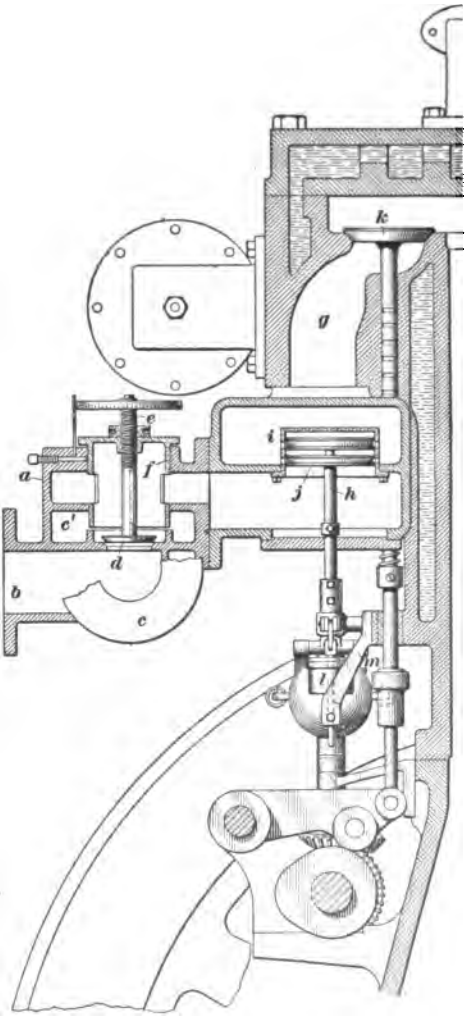


FIG. 12

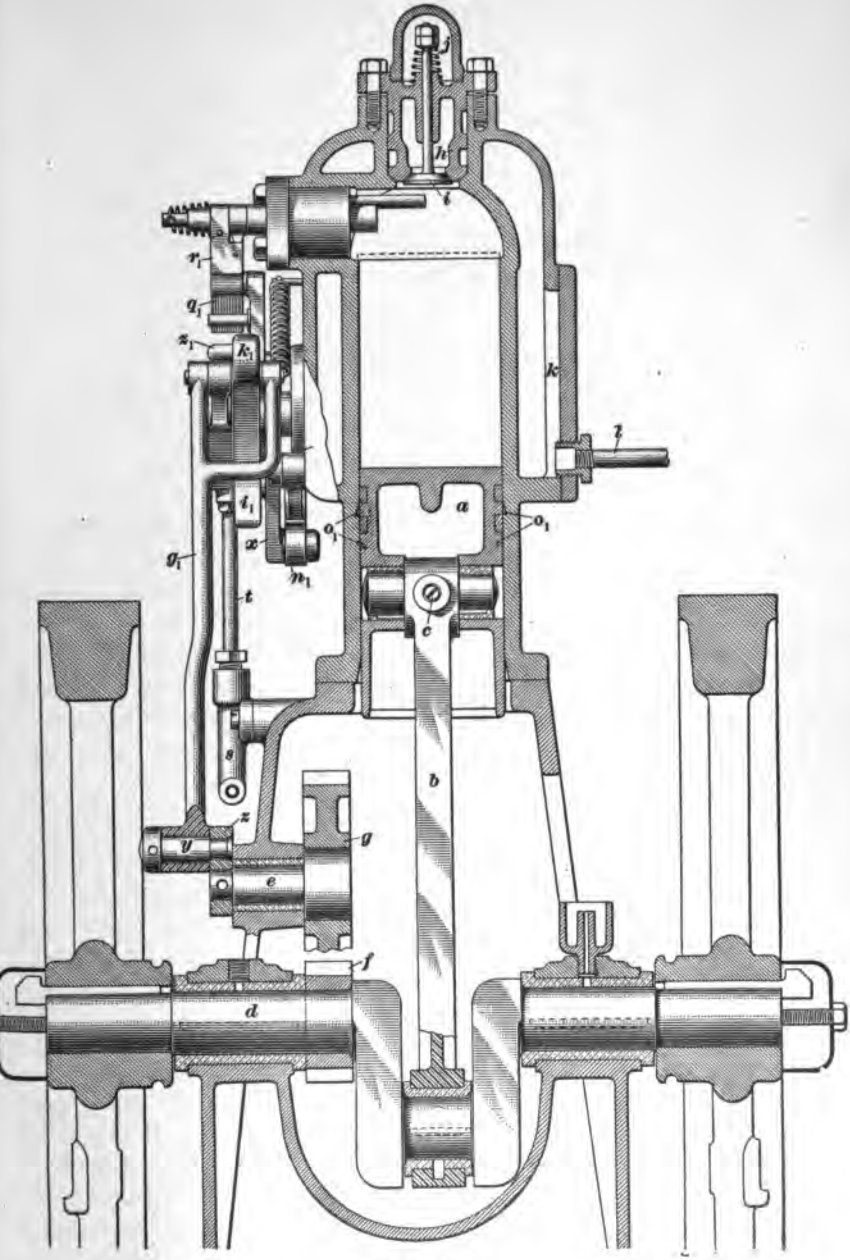


FIG. 13

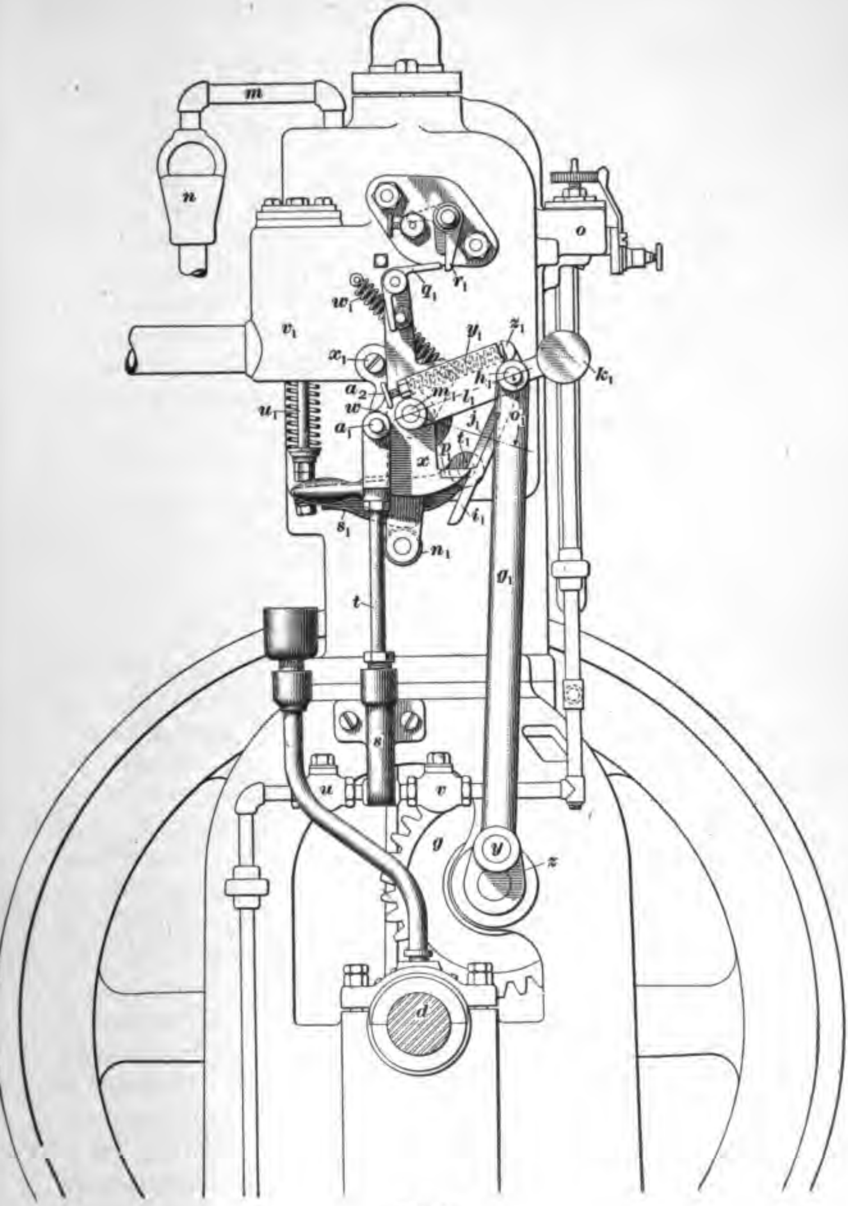
27. In order to prevent an unsteady motion of the governor, the governor balls are provided with dashpots *l* attached to the brackets *m*, the piston working in the dashpot being fastened to the governor balls. The main inlet valve *k* is operated in the same manner as in the case of the hit-or-miss method of governing, and opens to its full extent at every revolution of the cam-shaft.

SINGLE-ACTING GASOLINE ENGINE

28. General Arrangement.—A small-sized gasoline engine of the single-acting type, governing by the hit-or-miss method, is illustrated in Figs. 13, 14, and 15. Fig. 13 is a vertical section, on the plane of the axis of the crank-shaft, through the engine bed, cylinder, and inlet valve; while Fig. 14 represents a side elevation showing the mechanism for operating the gasoline pump, exhaust valve, igniter, and governor. The piston *a*, Fig. 13, is shown in its lowest position, at the end of either the suction or the expansion stroke. The connecting-rod *b*, instead of turning on the piston pin, is firmly clamped to it by the screw *c*, the piston pin having its bearings in bronze-bushed holes in the piston.

29. The Inlet Valve.—The inlet-valve casing *h* is in the top of the cylinder, and the valve *i* is automatic in its action, being opened by the suction, during the first downward stroke of the piston, against the tension of the light coil spring *j*, which causes the valve to close as soon as the piston starts on the first upward, or compression, stroke. The cap over the spring tends to diminish the noise caused by the seating of the valve in its casing.

30. Cylinder and Water-Jacket.—The cylinder and the water-jacket of this engine are cast in one piece, the opening *k* being provided for the purpose of cleaning the casting and facilitating the removal of deposits that accumulate in the water space. The cooling water enters the jacket at the lowest point through the supply pipe *l*, and leaves the


m
n
o
v_1
w_1
q_1
r_1
y_1
z_1
x_1
h_1
k_1
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l_1
w
u_1
j_1
o_1
a_1
t_1
p_1
x
i_1
s_1
n_1
g_1
t
s
u
v
g
y
z
d

FIG. 14

cylinder at the top through the overflow pipe *m*, Fig. 14, connected to the funnel *n* and to the drain pipe. Oil grooves o_1, Figs. 13 and 14, in the piston and wall of the cylinder are provided, as shown.

31. Air and Fuel Supply.—The air supply is taken from the space in the engine bed below the cylinder, and is carried to the inlet valve through a port or passage running along the right side of the cylinder, Fig. 15, to which the gasoline valve *o* is attached. Fig. 15 is a section through the air passage, showing the method of introducing the fuel into the air-current and the admission of the mixture through the

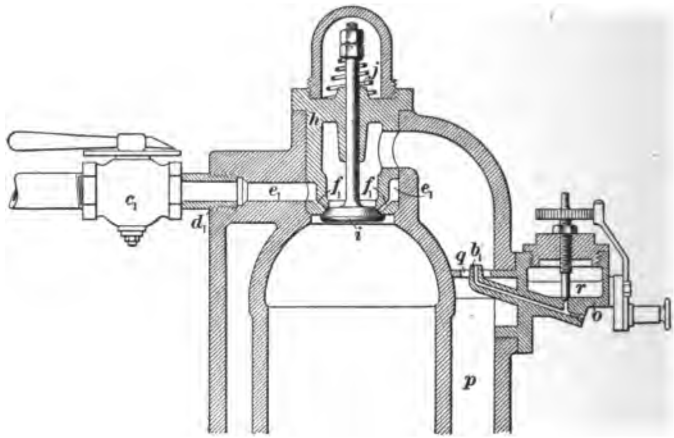


FIG. 15

inlet valve to the cylinder. The air passes upwards through the passage *p*, and its velocity is increased while going through the restricted area *q* in the gasoline valve *o*. The fuel is delivered to the reservoir *r* by means of the gasoline pump *s*, Fig. 14, attached to the side of the engine bed. The pump consists of a cylinder *s*, a vertical plunger *t*, and check-valves *u* and *v* in the suction and discharge pipes. The plunger is operated by an extension *w* of the igniter lever *x*, which receives its movement from the crankpin *y* fastened to a disk *z* on the gear-shaft *e*, Fig. 13. Before starting, gasoline is pumped from the tank into the gasoline valve *o* by moving

the plunger t up and down by hand, which can be done after removing the pin a_1 in the lever arm.

32. The level of the gasoline in the reservoir r, Fig. 15, is kept constant by a wall that divides the interior of the casing into two spaces. The supply pipe delivers the gasoline into one part, and an overflow pipe carries off the surplus gasoline that flows over the partition into the other part and returns it to the storage tank. The nozzle b_1, through which the gasoline is sprayed into the air-current, is elevated slightly above the level of the gasoline in the reservoir, so that no gasoline can run into the engine cylinder unless it is drawn out of the nozzle by the air suction, which is strongest at the point q, where the gasoline-valve extension projects into the air passage.

33. Action of Governor and Igniter.—The valve mechanism, igniter, and governor operate as follows: The connecting-rod g_1, Fig. 14, attached to the revolving crankpin y, is forked at its upper end and, on the pin h_1 passing through the fork, carries the governor lever i_1, with the steel blade j_1 and the governor weight k_1, as well as the connecting lever l_1. The latter is pivoted on the outer end of the pin m_1, while on the same pin, but closer to the cylinder, is pivoted the igniter lever x. The lower arm of the igniter lever carries the exhaust roller n_1. When the crankpin y revolves, the upper end of the connecting-rod g_1 swings the connecting lever l_1 through the arc o_1. While the speed of the engine is normal, the weight k_1 of the governor permits the blade j_1 to engage a similar blade p_1 on the igniter lever x, so that the lever is moved on its pivot pin m_1. In doing so, the upper end of the lever x carrying the steel angle blade q_1 actuates the lever r_1 of the igniter so as to produce the spark that ignites the charge.

34. At the same time, the lower arm of the lever x carrying the roller n_1 swings toward the left until the roller reaches the end of the curved surface of the exhaust lever s_1 pivoted at t_1. As a result, when the roller strikes the straight part of the lower surface of the lever s_1, the roller lifts the

exhaust lever, and this lever in turn opens the exhaust valve u_1 in the casing v_1. The shape of the curve of the lever s_1 is such that the roller does not begin to lift the exhaust valve until near the end of the expansion stroke. When the movement of the crank y starts the connecting lever l_1 on the up, or return, stroke, the tension of the coil spring w_1 attached to the igniter lever x, pulls back the lever, so that the blades j_1 and p_1 remain in contact.

The movement for the valve and igniter mechanism is transmitted from the crank-shaft d, Fig. 13, to the gear-shaft e by means of the pinion f and the gear g, the ratio of the gear diameters being 1 to 2, the gear-shaft running at one-half the speed of the crank-shaft.

35. If the speed exceeds the normal, the inertia of the weight k_1, Fig. 14, causes the governor lever i_1 to turn on its pin h_1 until the blade j_1 is disengaged from the blade p_1 and the lever x remains stationary, resting against the stop-pin x_1. The governor thus controls both the exhaust and the ignition, causing them to be put out of action whenever the load is light and the speed rises. A light coil spring y_1 exerts pressure against the projection z_1 of the governor lever i_1, and by tightening or loosening the setscrew a_1 the speed can be varied at will.

36. While the exhaust valve is kept closed and the igniter out of action by the governor, the charge previously admitted to the cylinder remains in the combustion chamber without being exploded. As soon as the action of the governor permits the blade j_1 to catch the blade p_1 again, this charge is fired, and the engine continues on its regular cycle of operations until the governor again prevents the ignition and exhaust.

37. Changes Required When Using Gas.—When using gas instead of gasoline, the opening in the side of the cylinder to which the gasoline valve is attached is closed by a plain cover, and a gas-supply pipe and a throttle cock c_1, Fig. 15, are attached to the upper part of the cylinder at d_1. A horizontal port connects the gas-supply pipe to the space e,

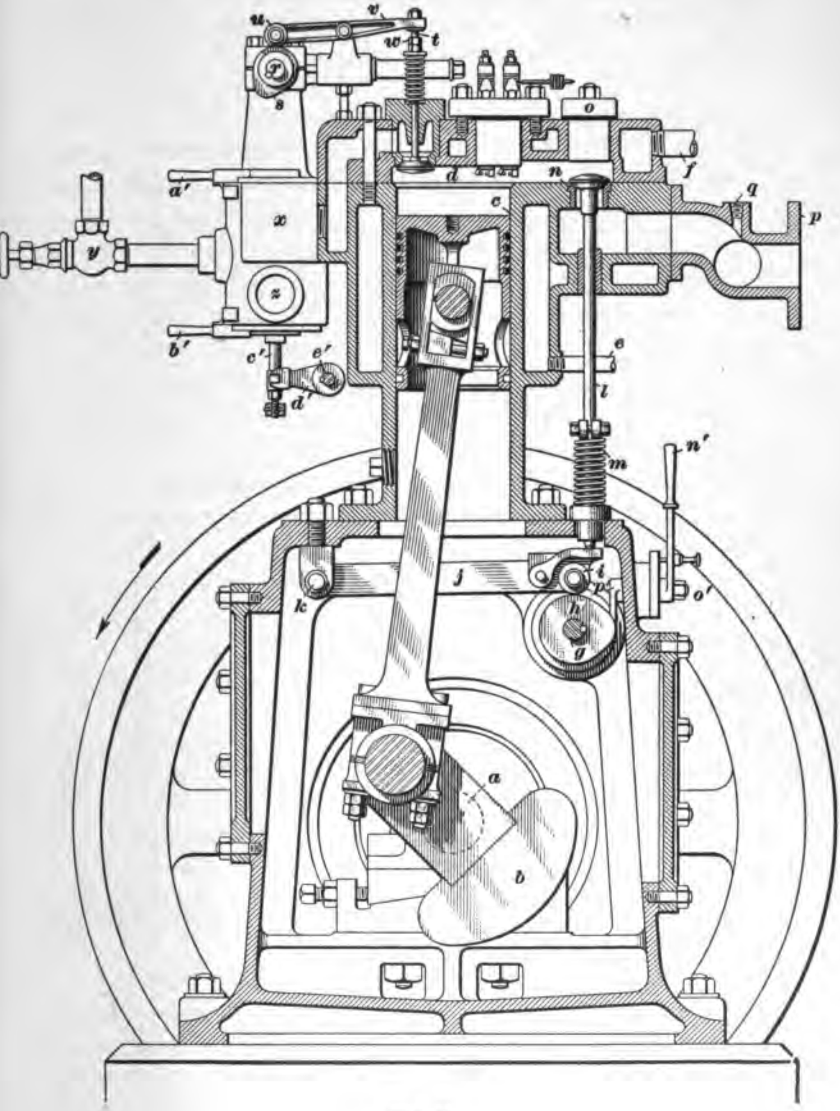


FIG. 16

around the body of the inlet valve *h*, and the gas is mixed with the air as it passes into the inlet valve through a number of small holes, as shown at $f_1 f_1$.

TWO- OR THREE-CYLINDER GAS ENGINE

38. A vertical four-cycle engine of either the two- or the three-cylinder type, in which the governor varies the volume of the charge according to the load, is shown in Figs. 16 and 17. The cranks of the two-cylinder engine are in line with each other, and the valves and igniters are timed so that an impulse is given to one of the cylinders at every revolution; while in the three-cylinder engine the impulses are only two-thirds of a revolution apart, the cranks being at an angle of 120°.

39. Fig. 16 represents a vertical transverse section through one of the cylinders, showing the main working

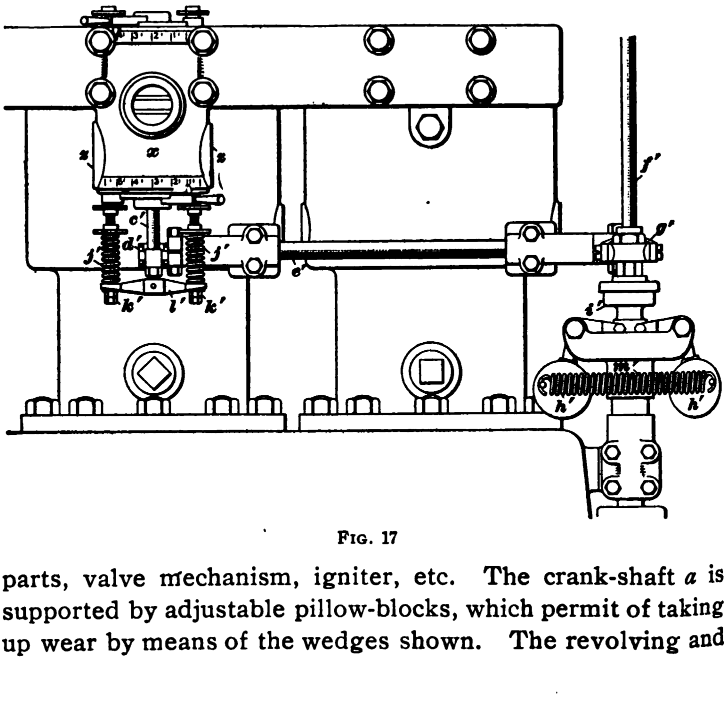


FIG. 17

parts, valve mechanism, igniter, etc. The crank-shaft *a* is supported by adjustable pillow-blocks, which permit of taking up wear by means of the wedges shown. The revolving and

reciprocating parts are balanced by the weights *b* bolted to the cranks opposite the crankpin. The cylinder *c* is water-cooled, the water-jacket extending also around the exhaust-valve casing, and the openings in the cylinder head *d* containing the inlet valve and igniter. The cooling water enters the lower part of the jacket through the pipe *e* and leaves the cylinder head through the overflow pipe *f*.

40. **Valve Connections.**—The exhaust cam-shaft *g* revolves at one-half the number of revolutions of the crank-shaft, and operates the exhaust valve by means of a cam *h*, which lifts a roller *i* on the free end of the exhaust lever *j* pivoted at *k*. The upper side of this lever comes in contact with the lower end of the vertical exhaust-valve stem *l*, which is kept on its seat by the pressure of the spring *m*. The seat *n* of the exhaust valve can be replaced in case of wear, while the cover *o*, when removed, permits the valve to be taken out for the purpose of inspection and cleaning. The exhaust pipe is connected to the flange *p*, while *q* is an opening through which water is admitted to the exhaust pipe to deaden the noise of the escaping gases. A pair of bevel gears on the end of the shaft *g* drives an intermediate horizontal shaft, which in turn transmits the motion to a vertical shaft on the opposite side of the engine. The vertical shaft drives an upper cam-shaft *r* fitted with two cams for each cylinder; namely, the cam *s* operating the inlet valve *t* by lifting the roller *u* on the end of the rocker-arm *v*, and the cam for operating the igniter, which will be considered later. The screw and locknut *w* serve to take up any wear or play between the lever and the valve stem.

41. **Fuel Supply and Regulation.**—The regulation of the engine is effected by a flyball governor, a detail of which is shown in Fig. 17. The governor varies the quantity of the mixture according to the changes in the load on the engine, the quality of the mixture being always the same, and an impulse being given to the piston at every other revolution of the crank-shaft at all loads.

Before reaching the inlet valve, the combustible mixture is formed by the gas and air entering a mixing chamber *x*, Fig. 16, in properly regulated quantities, which can be adjusted, as explained later, according to the quality of the fuel available in different localities.

42. One mixing valve serves for either two or three cylinders, Fig. 17 showing the valve attached to the middle cylinder of a three-cylinder engine, with connections extending both ways to the right- and left-hand cylinders. The air-supply pipe is connected to the lower part of the mixing valve, as indicated, while the gas enters the valve through a pipe provided with a valve *y*, Fig. 16, attached above the air connection *z*. The proportion of gas and air is indicated by the positions of the two hand levers: a' at the top for gas, and b' at the bottom for air, both levers having pointers swinging over graduated arcs on the upper and lower finished collars of the mixing-valve casing *x*. By means of these scales, the operator is always able not only to judge the proportion of air and gas in the mixture admitted to the cylinder, but also to correct the composition of the charge if the quality of the fuel or the pressure at which it is delivered vary to any appreciable extent.

43. The mixing valve consists of an outer cylindrical casing with openings corresponding to ports in the mixing-valve connections leading to the cylinders. Into this casing is fitted a stationary cylindrical sleeve, the walls of which are provided with ports opening into an annular space surrounding the sleeve except a short distance at the top and bottom. A hollow piston, provided with ports that register with the ports in the sleeve, is attached to the mixing-valve stem c', the end of which is attached to the lever d' keyed to the shaft e', Figs. 16 and 17.

44. The governor, which is of the centrifugal flyball type, is mounted on the vertical shaft f', Fig. 17, which transmits the motion from the lower to the upper cam-shaft. A lever connection at g' causes the horizontal shaft e' to turn in its bearings when the centrifugal force of the governor balls h'

causes the governor sleeve i' to move vertically on the shaft f'. The lever d', Fig. 16, fastened to the shaft e' and engaging the valve stem c', raises or lowers the cylindrical piston in the mixing valve, and thereby changes the relative position of the ports in the stationary sleeve and the sliding piston of the mixing valve, thus varying the amount of combustible mixture admitted under all conditions of load through the ports connecting with the passages leading to the cylinders. The valve stem and piston are lifted by the action of the governor against the tension of the springs j', j', Fig. 17, which may be adjusted by means of the locknuts k', k', and are connected by the yoke l'. The speed is regulated by the governor-ball springs m', the tension of which can be adjusted so as to give a certain range of speed if desired.

45. Starting by Compressed Air.—Compressed air, taken from a storage tank charged to about 120 pounds pressure, is used for starting the engine. A separate cam-operated inlet valve is used for the admission of compressed air into one of the cylinders. The valve is timed so as to admit air pressure at every downward stroke of the piston, the regular inlet valve being temporarily thrown out of operation by shifting the inlet-valve roller u, Fig. 16, out of the path of the inlet cam s. A hand lever n', attached to the side of the crank-case, is fastened to the pin o', extending into the case and carrying on its inner end a lever p', which engages a groove in the exhaust cam-sleeve. By moving the hand lever, the exhaust cam-sleeve is shifted on the shaft g so as to render the regular exhaust cam h inoperative and cause the exhaust-valve stem l to be lifted by two auxiliary exhaust cams at every upward stroke of the piston. During starting, the cylinder operated in this way is therefore temporarily converted into an air motor. After a few revolutions, during which the regular mixture is admitted and exploded in the other cylinder or cylinders, the air supply is shut off and the inlet-valve roller and exhaust-valve cam are shifted back into their normal positions, when the cylinder will resume its regular functions.

46. Current for the igniter is supplied either by a battery or by a dynamo, in connection with the usual spark coil. If a dynamo is used, a small storage battery furnishes the current necessary for starting, the dynamo being put in service as soon as the engine comes up to speed.

Lubrication of the main bearings, crankpin, cylinder, and piston is accomplished by the projecting nuts on the connecting-rod studs dipping into the oil contained in the bottom of the crank-case and throwing a liberal amount of oil over the moving parts.

SINGLE-ACTING OIL ENGINE

47. General Construction.—A vertical four-cycle engine, known as the **American Diesel engine,** is illustrated in Figs. 18, 19, and 20. The principles on which the design of this engine is based are explained in *Principles of the Gas Engine.* The original form, which was built in Germany, has been modified in American practice by employing a separate belt-driven compressor for compressing the air that sprays the fuel into the combustion chamber. This engine has been placed on the American market in sizes of from 40 to 450 horsepower. It is essentially an oil engine, being adapted for the cheaper and less volatile grades of liquid fuels, such as crude oil, fuel oil, and distillates that cannot be used in the ordinary gasoline engine without first gasifying the fuel. There are two distinguishing characteristics of the Diesel engine, as follows: (1) During the compression stroke, the cylinder contains air only, admitted during the suction stroke and then compressed to such a degree that the resulting temperature reaches a point amply sufficient to burn any liquid fuel injected into it. (2) There is not, properly speaking, an explosion, such as takes place in the ordinary internal-combustion engine; the fuel, being burned as it is introduced into the compressed air, does not increase the pressure and temperature due to compression.

48. Fig. 18 is a sectional view through the cylinder, showing the design of the bed, main bearings, housing or

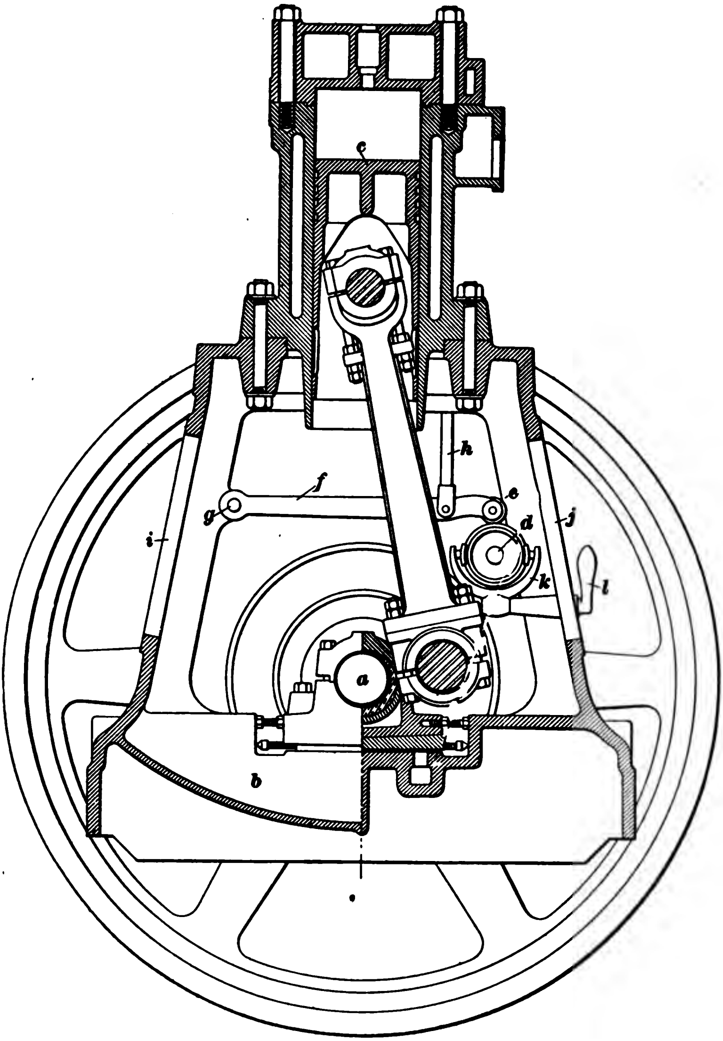


FIG. 18

cylinder support, cylinder, piston, connecting-rod, and cylinder head. The main bearings of the crank-shaft *a* are bolted to the bed *b*, and permit of adjustment, both vertically and horizontally, by means of wedges and setscrews. The main bearing boxes, as well as the connecting-rod boxes,

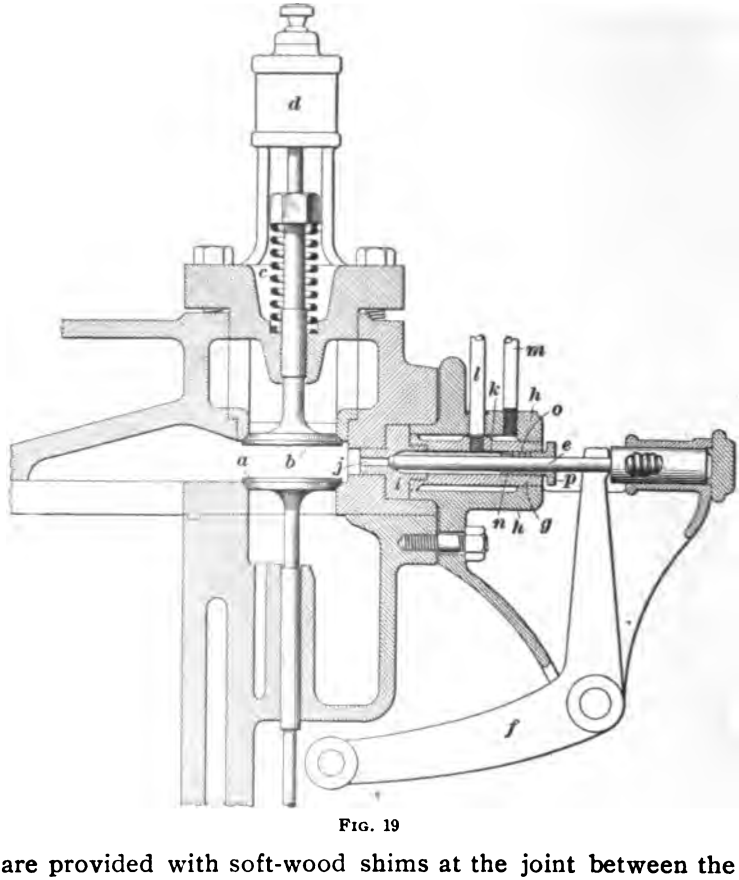


FIG. 19

are provided with soft-wood shims at the joint between the bearing and the cap, to permit lost motion to be taken up, in case of wear, by reducing the thickness of the shims. The proportions of the crank-shaft, bed, and connecting-rod are necessarily somewhat heavier than in the ordinary four-cycle engine, owing to the high pressures under which the

Diesel engine operates. The piston *c* is unusually long, with a view of reducing wear of the cylinder to the smallest amount.

49. Inlet and Exhaust Valves.—A sectional view of the admission and exhaust valves is shown in Fig. 19. The exhaust valve *a* is operated from a cam on the secondary shaft *d*, Fig. 18, rotated by spur gears at one-half the number of revolutions of the crank-shaft *a*. The exhaust cam engages the roller *e* on the end of the lever *f*, which is pivoted on the pin *g* and lifts the exhaust valve by means of the connecting link *h*. The inlet valve *b*, Fig. 19, which admits the air required to support combustion, is automatic in its action, being opened by the partial vacuum in the cylinder during the suction stroke and closed by the tension of the spring *c*. The upper end of the air-valve casing forms a dashpot *d*, in which air is admitted during the downward stroke of the valve and partly compressed and expelled through a small vent hole when the valve returns to its seat.

50. Fuel-Oil Admission.—The fuel is injected into the combustion chamber through the positively operated needle valve *e*, Fig. 19, actuated by a cam on the secondary shaft through the lever *f*. This valve is opened at the end of the compression stroke, when the air admitted during the suction stroke has been compressed to about 500 pounds per square inch. In order to introduce the fuel successfully into the highly compressed contents of the cylinder, the oil is forced into the clearance space with air under pressure. This air is furnished, at a pressure of about 700 pounds per square inch, by a separate compressor, driven by belt either from the engine or from a convenient shaft. The temperature of the air in the engine cylinder after compression is about 1,000° F., which is considerably above that required to ignite the mixture by spontaneous combustion, without the use of any special igniting apparatus. Owing to the high temperature of the compressed air in the cylinder at the time the fuel is injected, it is evident that the combustion will be practically complete, leaving no residue and rendering the exhaust gases clean.

51. The fuel valve consists of a bushing *g*, Fig. 19, pressed into the casing *h*, which is supplied with a nut *i* that forms the nozzle *j*. Inside of the bushing are small brass washers *k*, with numerous small holes through them, through which the fuel oil passes. The fuel enters the valve through a pipe, not shown, on the side of the casing *h* and in front of

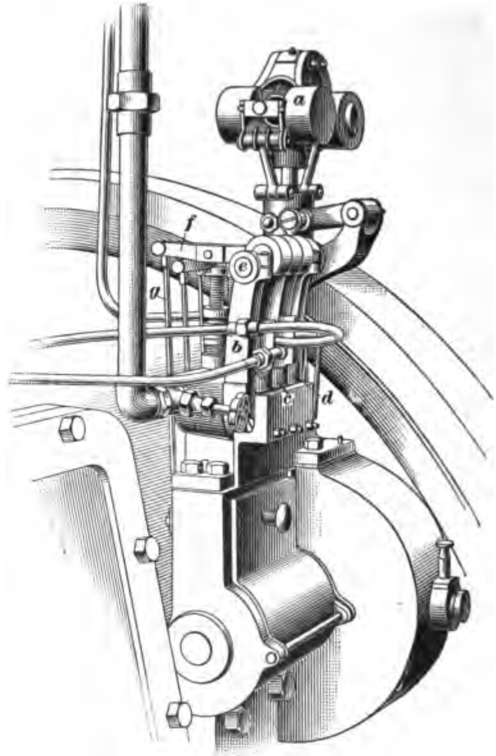


Fig. 20

the vertical air pipe *l*, through which the compressed air enters the atomizer. The oil enters the space surrounding the valve stem *e*, and is finally atomized by being forced through the small holes in the brass washers, entering the combustion chamber through the nozzle in the form of a very fine spray. The air-injection pipe *l* is screwed into the bushing *g* and is calked into the casing with soft metal,

so as to leave the space around the bushing water-tight. Cooling water is supplied to this space by a pipe not shown, and leaves through the vertical pipe *m*.

The outer end of the bushing *g* is provided with a metal ring *n* that rests against a shoulder, packing rings *o*, and a gland *p* that forces the packing against the metal ring so as to make a tight joint around the needle valve *e*.

52. Governing of Fuel Supply.—The centrifugal governor *a*, Fig. 20, controls the fuel pumps and thus the amount of oil supplied to each cylinder. In the figure is shown an oil pump with three plungers *b*, *c*, and *d*, one for each cylinder of a three-cylinder engine. The pump cylinders are provided with by-pass valves that, when open, permit a portion of the oil to return to the suction side of the pump instead of going to the engine by way of the delivery pipe from the pump to the fuel-admission valve. The period of time during which the by-pass valves are kept open is controlled by the governor, which raises or lowers a shaft acting as a pivot for the arms *f* that open the by-pass valves. These arms are moved at one end by means of the connecting-rods *g* attached to eccentrics on the pump driving shaft. By raising or lowering the pivot shaft, the time during which the valves are open is regulated.

53. The fuel admission valve *e*, Fig. 19, is open during about one-tenth of the working stroke. Under light load, oil is admitted during only a portion of this time, compressed air only entering during the remainder of the period, but not in sufficient quantities to increase the pressure in the cylinder to any appreciable extent.

54. Lubrication.—The lubrication of the piston, crankpin, and main bearings is effected by the splash system of oiling, the lubricant, the quality of which depends on the size of the engine and the length of the run, being poured into the crank-case. The level of the oil is then raised to the proper height by the addition of a sufficient quantity of water to bring the oil to within about 1 inch of the center of the crankpin bearing when the crank stands in its lowest

position. The cylinder support is provided with removable doors that close the openings *i* and *j*, Fig. 18, and that, when opened, give ready access for the purposes of inspection, adjustment, and repair of the bearings.

55. Method of Starting.—The engine is started by the use of compressed air taken from the tank supplied by the compressor. Fig. 18 shows a fork *k*, which is moved by means of a handle *l* and shifts a cam-sleeve on the shaft *d* so as to cause a starting cam to engage a starting valve that admits compressed air to one of the cylinders. After two or three revolutions of the main shaft, the other cylinders compress their respective charges of air sufficiently to ignite the fuel admitted to them in the regular manner, as already described. As soon as this occurs, the starting handle is released, and the starting valve is automatically rendered inoperative, while the regular admission and exhaust valves resume their normal functions.

STATIONARY GAS-ENGINE AUXILIARIES

STARTING DEVICES

METHODS OF STARTING

56. Since the gas engine does not derive its power from an external source of pressure, it becomes necessary to adopt some means of starting it before it will pick up its cycle of operations. When the engine is not too large, it is commonly started simply by turning it over by hand with the gas valve opened, thus causing the valves and igniter to go through their regular motions until a charge of the right proportions is taken in, compressed, and ignited. After the first explosion, the engine will run itself, enough momentum being given to the flywheel by the first impulse to carry it through the subsequent revolutions and the next compression stroke.

57. Often, the effort of overcoming a high compression, when turning the flywheel by hand, is lessened by letting a portion of the charge escape through a relief valve located in the side of the cylinder about the middle of the stroke, so that the opening is covered by the piston after a suitable portion of the charge has escaped. In larger engines, and where it is objectionable to let inflammable gas escape into the atmosphere near the engine, there is sometimes provided a special starting cam, which acts on the exhaust valve to hold it open during the first portion of the compression stroke. After the engine has started, this cam is shifted out of action by hand.

58. Large engines are most often started by compressed air, which is compressed by an air pump operated by the engine, and stored in a suitable tank until used. When it is desired to start the engine, the compressed air is admitted to the cylinder by a special valve, which is generally operated by the two-to-one cam-shaft and a special sliding cam that can be shifted on a feather to put it out of action until needed. This cam admits air during the first part of both the suction and expansion strokes, and the exhaust valve is held open by another special cam during what is ordinarily the compression stroke. Thus, an impulse is obtained at each revolution until the flywheel has gathered the momentum necessary to carry the engine through its cycle. This method of starting is used principally with engines having more than one cylinder, one cylinder only being arranged for using compressed air. In this manner, the engine is run for a few revolutions on compressed air until the other cylinders take up their work, when the valve cams are shifted to their running position.

59. Some large single-cylinder engines are started by turning over with the exhaust valve open, so as to interpose no resistance, until the crank is at the right position to begin the expansion stroke, when a cartridge of gunpowder is introduced into the combustion chamber by a suitable opening, and exploded, giving the engine a sufficient impulse to carry it over the next compression stroke.

60. A novel method of starting large engines, and one that requires no great amount of skill to handle, is the use of a smaller gas engine to turn the large engine over. The small gas engine is readily started by hand, and after starting, it is thrown into gear with the large engine. As soon as the larger engine has sufficient headway and has taken up its own cycle, the smaller engine is thrown out of gear. This method has the objection of being the most expensive, but it is the most reliable and has the advantage of always being ready.

61. When a gas engine is used to drive an electric plant, the engine may be started by means of the dynamo, in case current is available. The dynamo is operated as a motor until the engine is under way, when the dynamo circuit may be thrown open and need not be switched into the line until the engine is at full feed. A dynamo, when not supplying current, that is, when its circuit is open, requires very little power to drive it. Nearly all modern electric plants have a storage battery, and if there is no current available from an outside source, that from the battery may be used to start the engine.

62. Occasionally, the starting of an engine may be accomplished by the explosion of one charge, as follows: A charge of gas and air is drawn into the cylinder by turning the engine over until the piston is about half way on its forward stroke. The charge is then exploded, either by means of a special device or by snapping the electric igniter.

THE GUNPOWDER STARTER

63. One type of **detonator, or gunpowder, starter** is illustrated in Fig. 21. It has three essential parts: the cartridge barrel *b*, the cap *c*, and the firing pin *p*. It is, in fact, a device for discharging a shotgun cartridge into the compression space.

The cartridge *a* is a brass shotgun shell, loaded, first, with about a thimbleful of rifle powder *r*, and then filled with

blasting powder *f*. The powder is held in place by a plug *t* of tallow. The barrel *b* is screwed into the wall *d* of the compression space with a taper thread. The cartridge is

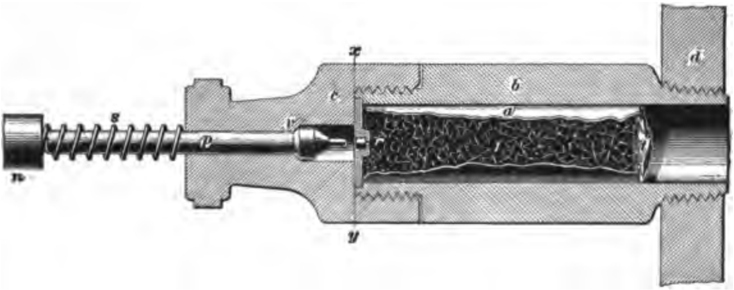


FIG. 21

placed in the barrel, and the cap *c*, containing the firing pin, is screwed over it on the end of *b*. The engineer must make

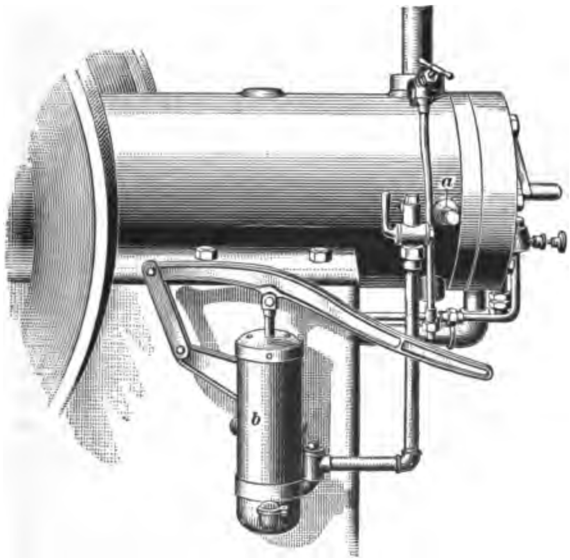


FIG. 22

sure, beforehand, that the point of *p* is at least $\frac{1}{32}$ inch back of the line *x y*, so that it will not come in contact with the primer when the cap is screwed into place. The spring *s* is

compressed about ¼ inch by the nut *n*, in order to hold *p* against the seat *v*.

To start the engine, the flywheel is turned over until the piston has compressed a charge and the crank is just past the inner center. Then the nut *n* is struck a smart blow with a hammer. The explosion of the powder fires the charge, and the combined force of both explosions is sufficient to carry the engine through several revolutions until it takes up its regular cycle.

64. The application of a detonator is shown in Fig. 22, where *a* is the detonator and *b* is a starting pump attached to the engine cylinder. The starting charge to be fired by the detonator is forced into the cylinder by the charging pump *b* after the detonator is put in place.

COMPRESSED-AIR STARTERS

65. A starting valve operated by compressed air is illustrated in the sectional view, Fig. 23. This valve consists of a casing *a* containing two poppet valves *b* and *c*, which are held to their seats by coil springs *d* and *e*. The poppet valves are opened by the operation of a hand lever *f* pivoted at *g*. The upper half of the casing *a* is connected to the combustion chamber by means of the pipe *h*, and is fitted with a cup *i* to receive a small quantity of gasoline. The lower valve opens or closes a connection *k* communicating with a compressed-air storage tank. The tank being filled, the engine is set in position for starting by turning the flywheels until the crank has just passed the inner dead center, the inlet and exhaust valves of the engine being closed. The gasoline cup *i* is filled and the gasoline admitted to the starting-valve casing by opening the cock *j*. The hand lever *f* is then pulled to the right, throwing the lower valve off its seat, and thus opening communication between the air tank and the combustion chamber. The pressure is sufficient to open the upper valve *b*, and the inrushing air vaporizes the gasoline and forms an explosive mixture that, on being ignited at the proper moment, gives

an impulse to the piston sufficient to turn the crank-shaft over several times until a regular charge is admitted and exploded.

In stopping the engine, the regular fuel supply is turned off and the hand lever *f* is pushed to the left, opening the upper valve and allowing the engine to act as a pump. On each suction stroke, a charge of air is taken into the cylinder and on the compression stroke it is compressed and forced into the air tank, the compression pressure in the engine cylinder being sufficient to overcome the tension of the lower spring *e* and force the lower poppet *c* from its seat. With the lever *f* in the position shown in Fig. 23, the pressure in the tank keeps the valve *c* closed.

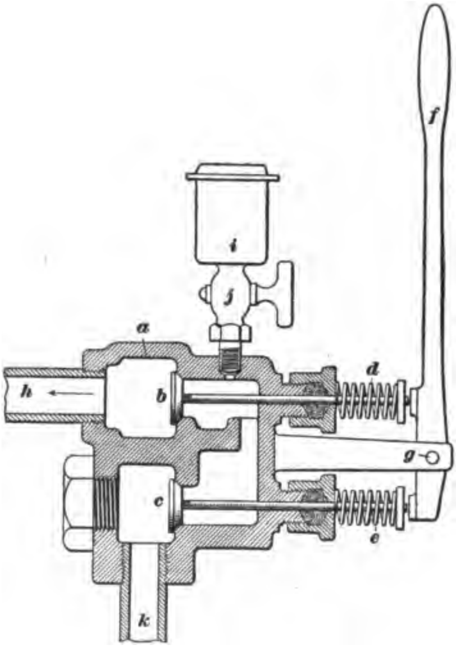


Fig. 23

66. Another form of self-starter, using either gasoline or gas, is shown in Fig. 24. It consists of a hand pump *a*, a vessel *b*, and pipe connections between the vessel and the combustion chamber *c*, of the engine. Its operation is as follows: The vent-cock *e* of the engine cylinder and the poppet valve *d* between the starting vessel and the cylinder are opened and the plug valve *f* between the vessel and the cylinder is closed. Having turned the engine into starting position, so that the crank has just passed the inner dead center, at the end of the compression stroke, the electric igniter is set so that the timing of the spark is delayed

until the crank has passed the center to the extent of about 10°. The receptacle or carbureter *g* is filled with gasoline, or, in the case of a gas starter, the gas-cock *h* is opened.

The mixture is tested by opening the plug valve *i* in the test tube *j* and the valve *k* and pumping two or three strokes while closing the end of the test tube with the left hand. On removing the hand from the tube, a lighted match is held to the end of the tube; then, if the mixture is of good quality, it will burn quickly downwards in the tube with a

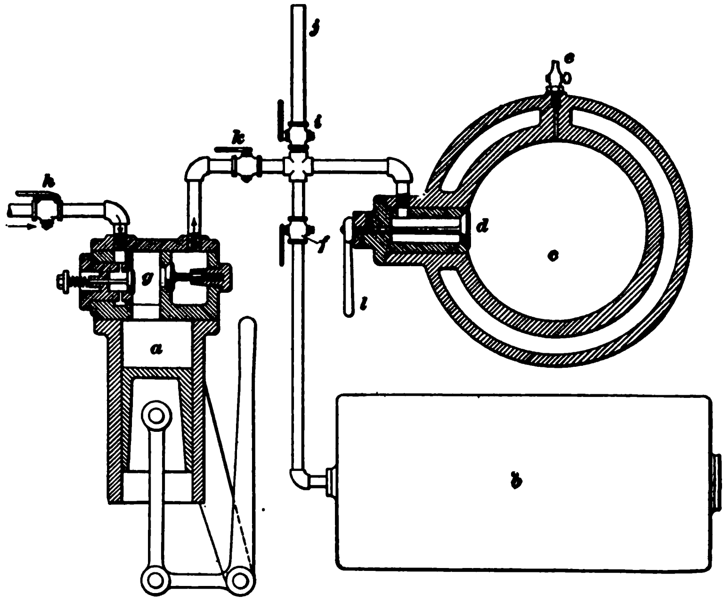


FIG. 24

sharp sound. If the mixture is poor in quality, it will burn slowly at the end of the tube with a yellow flame, or will refuse to burn at all. In that case, a different proportion of air and fuel should be tried, until the swift burning in the test tube shows the mixture to be of proper quality. The valve *i* is then closed, and a few strokes pumped by hand until all air or burned gases have been forced out of the cylinder *c* through the vent-cock *e*. The cock *e* is then closed

and pumping continued for about ten strokes. The handle *l* of the valve *d* is then moved so as to close the valve, and by opening the valve *f* and pumping about twenty strokes the pressure in the vessel *b* is increased over that in the combustion chamber. The valve *k* between the hand pump and the vessel *b* having been closed, it is ascertained whether the wires from the battery are properly connected to the engine, and whether the engine crank stands in a position just past the inner dead center, the electrodes of the igniter being ready to separate and produce the spark. The fuel-admission valve is then opened. Everything being in order, the valve *d* between the vessel *b* and the cylinder is opened, when the pressure of the air rushing from the vessel into the cylinder will move the piston sufficiently to cause the igniter to fire the charge in the cylinder. A powerful impulse is thus given to the crank, and on the next revolution, after the hand lever *l* has been moved back so as to close the valve *d*, the engine will start on its cycle of operations in the regular manner.

COOLING AND MUFFLING AUXILIARIES

WATER-COOLING SYSTEM

67. The need for circulating a stream of water, or in some cases a current of air, around the cylinders and combustion chamber of gas engines to protect them from overheating has already been pointed out. When cooling by means of water, the system is usually arranged so that the water enters the cylinder water-jacket near the bottom and leaves it at the extreme top, so that any steam formed will be carried out with the water. For stationary engines, the water may be obtained from the city water supply, or it may come from and return to a reservoir large enough to hold sufficient water so that it does not become overheated while the engine is running. When this is done, the reservoir is placed above the engine and the water passes from the bottom of the reservoir to the bottom of the water-jacket, and

from the top of the water-jacket to some point as near the top of the reservoir as possible, care being taken that the mouth of the pipe going into the reservoir is never uncovered. In this way, the water will circulate by gravity and no artificial circulation will be required unless the pipes are too small to carry the water freely.

Such a circulating system is shown in Fig. 25. The cylinder of the engine is shown at *a*, the water-supply tank at *b*, the supply pipe at *c*, and the waste pipe at *d*. When the

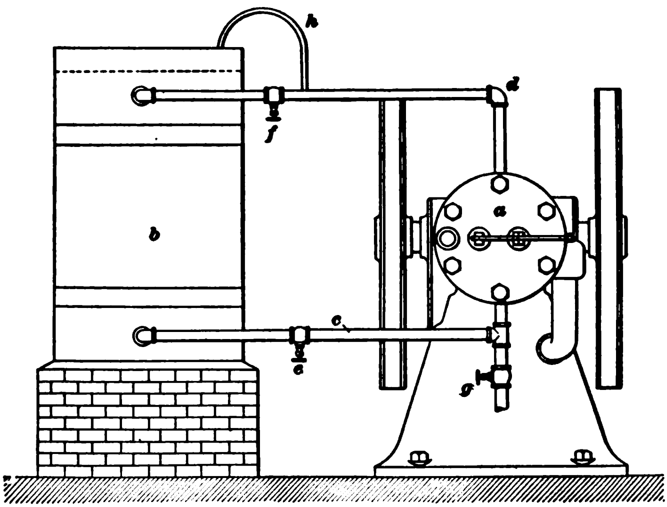


FIG. 25

engine is running, the valves *e* and *f* are open and the valve *g* closed. The water then circulates through the water-jacket, up through *d* and into the top of the tank. The valve *g* is provided for draining the water-jacket, and the small air pipe *h* permits the water to be quickly drained when the valves *e* and *f* are closed and the valve *g* opened.

68. The water passed through the engine jacket is often discharged into the exhaust pipe, where it serves most effectively to muffle the exhaust by cooling and therefore condensing the gases until their pressure is but little above that of the air. The water itself is partly vaporized and is blown

out by the force of the exhaust gases, even though the pipe runs up instead of down.

69. In very large engines, it becomes necessary to cool the exhaust valve by running water through a surrounding jacket to prevent the valve from heating to such a point as to cause preignition. It will be evident that the larger the engine, the greater is the liability of overheating this valve, owing to its large size and to the fact that, unless it is cooled, the only avenue of escape for its heat is by conduction through the valve seat and the stem. By keeping the exhaust valve cool, therefore, it is frequently possible to use a much higher compression than would otherwise be possible, and in consequence a greater efficiency results.

MUFFLERS

70. Any device that will lessen the noise produced by the exhaust is called a **muffler.** The principle on which all mufflers are constructed is solely that of reducing sound waves caused by the high velocity of the escaping gases. This is accomplished in almost every case by placing an enlarged chamber in the exhaust pipe, as illustrated in Fig. 26. The gas from the engine enters at one end, as at *a*,

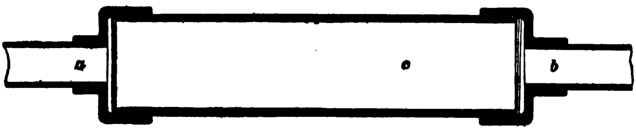


FIG. 26

expands in the chamber *c*, is cooled, and escapes through *b*. The velocity through *b* is much less than that through *a*, because it depends only on the difference of pressure between the gas in *c* and the pressure of the atmosphere; while, on the other hand, the gas is forced through *a* at a much higher velocity by the exhaust stroke of the piston.

Other forms of mufflers have the chamber *c* fitted with perforated plates or filled with twigs. A perforated cap is sometimes employed, instead of the pipe *b*. One firm of

gas-engine builders employs, on small engines, a rubber hose as a part of the exhaust pipe, the expansion of the hose serving the same purpose as the chamber *c*, Fig. 26.

71. It is of advantage to cool the muffler, either by passing a small stream of water through it, or by providing it with a water-jacket. Cooling the muffler increases its efficiency as a quieting device, as the exhaust gases are thus caused to contract on their passage to the outlet. It is also advisable to arrange the expansion chamber so that the inlet is not directly opposite the outlet, as, for instance, in the manner shown in Fig. 27, in which the exhaust enters the chamber *c* at *b* and leaves it at *a*. This arrangement prevents the gases from passing directly from *b* to *a*, so that the impetus of the exhaust is checked by the change of direction, without appreciably increasing the back pressure of the engine.

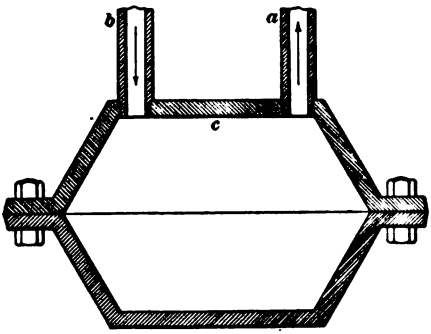


FIG. 27

HOT-TUBE IGNITION MECHANISM

72. In the earliest gas engines, an electric spark was used to fire the charge. Electricity being then comparatively little understood, the troubles experienced with this mode of ignition led to its being abandoned in favor, first, of the **slide-valve method of ignition**, and, later, of the **hot-tube method.** In the former system, a small reciprocating slide valve had a pocket that was put in communication alternately with the combustion chamber and the supply of fresh mixture. When this pocket had been filled with fresh mixture, it was brought by a further movement of the slide valve into contact with a small external flame, which ignited

it; and as the slide valve continued its movement the pocket was brought into communication with the combustion chamber, where the gas still burning in the pocket ignited the compressed charge. Small engines using this system of ignition may yet be found.

For stationary engines running at constant speed, hot-tube ignition is found to be very reliable, and has held its own until quite recent years, and is, in fact, not yet entirely discarded. It has, however, the objection of consuming 4 or 5 cubic feet of gas per hour, which adds a considerable percentage to the fuel bill of a small engine. Moreover, the enclosed flame, although shielded as far as possible, is still considered objectionable by some users. As the hot tube is ordinarily applied, it is impossible to determine exactly the time of ignition, and consequently the explosion may come a little too early or too late for the best performance of the engine. This is overcome in some engines by the use of a timing valve, but for the most part preference is now given to the electric spark. The reasons for this are obvious. With the exception of the heated-surface method, wherein sufficient heat is stored by the explosion of one charge to ignite the next, all types of heated igniters are more or less wasteful of gas. Of course, the proportion of this waste to the amount of gas used in the engine decreases as the volume in the cylinder grows larger, yet it always remains a more or less important item in the economy of the gas engine. Another advantage of electric ignition is that the charge can be fired at *exactly* the right time. No other method is absolutely reliable in this respect, although flame or tube igniters, having timing valves, are usually quite reliable under constant conditions of pressures and mixtures before ignition. No preliminary experimenting is required to determine the firing point, since the spark, being made in the compression space, fires the mixture at once, and no allowance has to be made for the propagation of a flame through a passage. Again, the time of ignition depends but little, if at all, on the condition of the mixture when fired by a spark in the body of the gas.

73. In the hot-tube system of ignition, an iron, nickel, or platinum tube having its outer end closed is screwed into the wall of the combustion chamber, so that the latter is in communication with the interior of the tube. This tube is heated constantly by means of a gas burner, the tube being kept at a red heat. During the exhaust and suction strokes, the tube is filled with burned gases; but toward the end of the compression stroke, these gases are compressed into the farther end of the tube, and the fresh mixture following them reaches the incandescent portion of the tube, where it is ignited and spreads the flame speedily to the rest of the charge.

74. A hot-tube igniter, with a timing valve, is shown in Fig. 28. The tube *t* is made of platinum, nickel, steel, porcelain, or wrought iron. By means of the flame *f*, the tube is kept at a temperature just high enough to ignite the charge. A somewhat careful regulation of this temperature is required, since, should the tube get too hot, its strength is impaired and the force of the explosion may cause it to burst. The regulation of the temperature is effected by adjusting the height of the burner *b*, or the height of the flame—preferably by the former method. The hottest part of the flame being close to the tip, the burner should be raised to lower the temperature of the tube, and lowered to raise the temperature of the tube. Communication with the compression space is obtained by means of the opening in the timing valve *a*. This valve opens, that is, the valve moves so that its opening stands over the passage to the igniter, at just the proper time for ignition, hence the term "timing" valve. At *g* is a small cock, used for clearing the tube of any accumulation of soot. When this cock is opened,

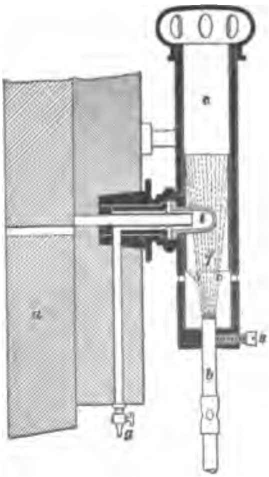


FIG. 28

one or two explosions will soon blow all the soot from the tube.

75. Fig. 29 shows an arrangement for hot-tube ignition *without* a timing valve. The tube *t* is heated in the usual manner by a flame from the burner *b*. The chimney *c*, together with the burner, can be adjusted by moving them along the rod *r*. This serves the purpose of adjusting the position of the incandescent portion of the tube at various distances from the cylinder. When the engine exhausts, the contents of the tube *t*, consisting of non-inflammable gases, rush out until the pressure within the tube is reduced to that

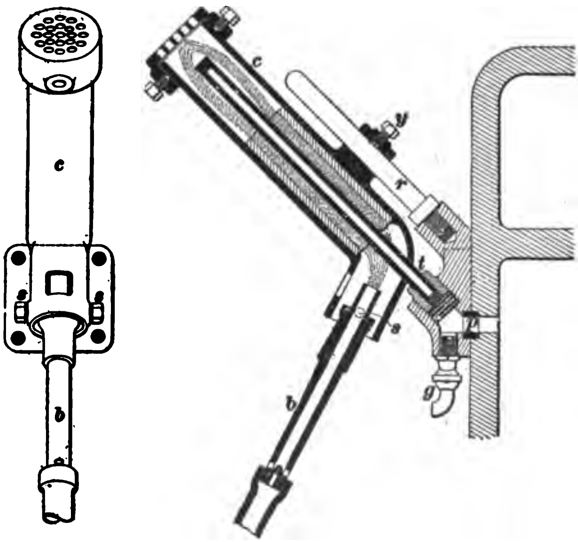


FIG. 29

of the atmosphere. On the compression of the new charge, this non-inflammable mixture is driven back up the tube, followed by the fresh, unburned gases. As soon as the combustible gas reaches the incandescent portion of the tube, it is ignited, and the explosion drives the flame out through the ignition port *p* to the compression space, where it fills the entire space. The setscrew *y* holds the chimney on the rod *r*. The burner is pivoted on the two screws *s*, so as to

permit the flame to be adjusted about the tube. At *g* is the usual cock for clearing the tube of soot.

76. In hot-tube igniters of this kind, the adjustment of the flame is a matter requiring skill and experience, and can be accomplished only by trial. A general rule is: Move the burner up the rod *r* if the charge fires too soon, or down the rod if ignition takes place too late. Some engines have open-tube igniters without adjustable burners. The makers of such engines adjust the burner by trial before the engine leaves the factory.

In some varieties of the hot-tube igniter, there is no external flame; the exploding charge heats a metal surface to incandescence, and the temperature of the surface remains at a point sufficiently high to ignite the succeeding charge. A suitable form of burner is used to heat the metal surface before starting the engine, after which it needs no further attention. This method of ignition has found great favor among oil-engine manufacturers, but is rarely or never used in modern gas-engine practice.

GAS-ENGINE DETAILS

ESSENTIAL PARTS OF GAS ENGINES

1. The different constructions of leading types of gas engines have been illustrated and described in preceding Sections. These descriptions, however, deal with the engine parts in a general way, rather than with their details. It is the object of this and succeeding Sections to explain the construction of some of the most important of these parts, in order that the various forms in which devices for accomplishing similar purposes are made may be understood. Owing to the large number of designs, it is impossible to describe the details of the parts of all engines. However, a sufficient number of different constructions have been selected to enable the student to understand, without difficulty, other forms in use.

GAS-ENGINE CYLINDERS

CONSTRUCTION OF CYLINDERS

2. Cylinder, Head, and Jacket in One Casting.—A sectional view of a small vertical gas engine of the two-cycle type, having the cylinder *a*, head *b*, and water-jacket *c* cast in one piece, is shown in Fig. 1. Small one-piece cylinder castings can be made satisfactorily, but it is not good practice to use such castings for engines of large size. The object of casting the cylinder, head, and jacket in one

piece is to avoid packing joints between the cylinder and head and between the cylinder and water-jacket.

Cylinders of stationary horizontal gas and gasoline engines of the four-cycle type are sometimes cast with water passages cored in the sides and head, as shown in Fig. 2. In this case, a cover *a* carrying the igniter plug *b* is bolted to the head and a cover ring *c* is bolted to the crank end of the water-jacket. The inlet valve is located at *d* and the exhaust valve at *e*. The ring *c* provides a convenient means of cleaning the water-jacket of any dirt or sediment that may accumulate from the use of dirty or impure water. Since the water pressure in the water-jacket is small, ordinary packing is used to keep the joint tight.

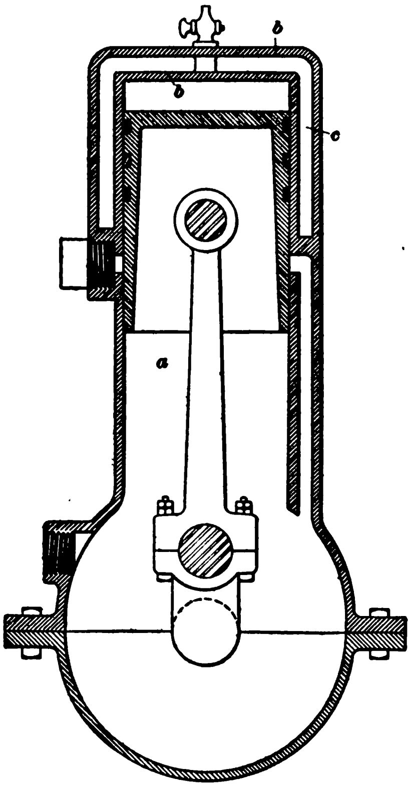


Fig. 1

An outside view of this cylinder is shown in Fig. 3. The opening *a* is for the igniter; that on top, at *d*, is for the inlet valve, and a corresponding one at *e*, at the bottom, is for the exhaust valve. The gas-inlet pipe is connected to the opening shown at *f* and the exhaust pipe at *g*; chambers are cored from these openings to the valves. At *h* is an oil hole, and at *i* is the outlet for the cooling water as it leaves the water-jacket. On each side of the cylinder there is a bracket like the one shown at *j*, by means of which the cylinder is bolted to the frame or engine bed.

3. There are disadvantages as well as advantages in having the cylinder, head, and water-jacket cast in one piece. Some of the disadvantages of this construction are the difficulty or impossibility of determining the thickness of metal

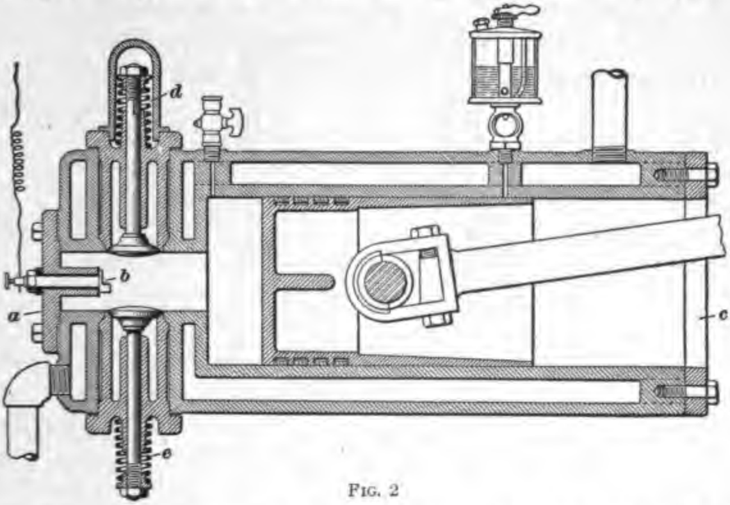


FIG. 2

in the cylinder walls or water-jacket and the difficulty of inspecting the closed end of the cylinder when machining, or when it is suspected that there is an accumulation of carbon

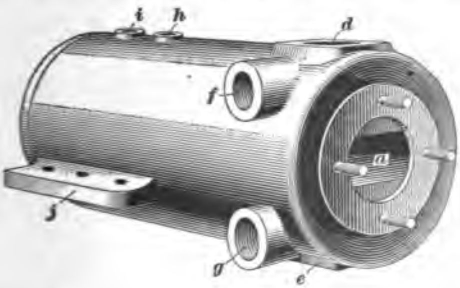


FIG. 3

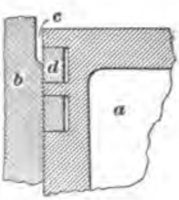


FIG. 4

in the combustion chamber. Casting the head and cylinder in one piece also makes it difficult to counterbore the cylinder, that is, bore it slightly larger at the head end, and secure a good finished surface. In Fig. 4 is shown a section *a*

of a part of the piston; at *b*, a sectional view of part of the cylinder is given, showing the counterbore *c*, or the portion

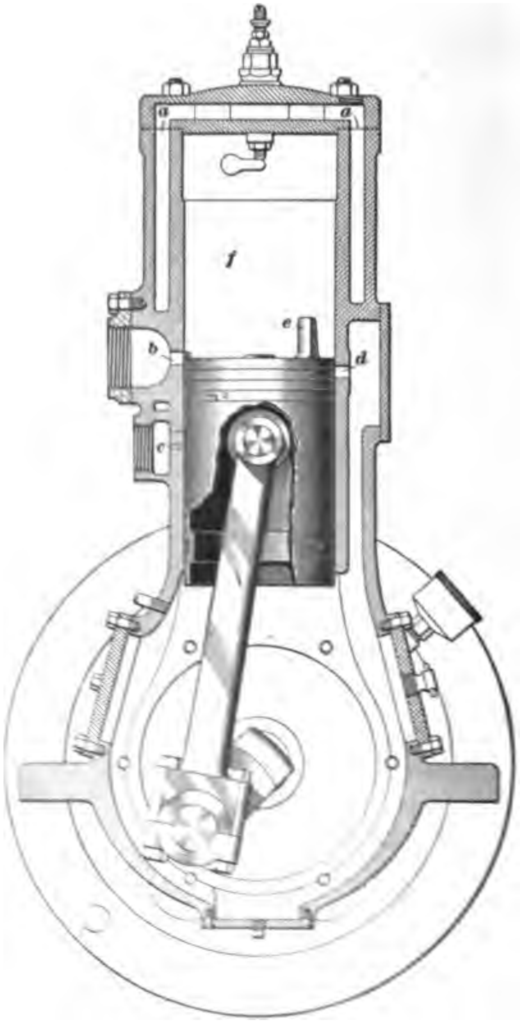


FIG. 5 (a)

of the cylinder bored to a slightly greater diameter than that in which the piston fits, so that, as the surface of the cylinder

wears away, it will not leave a shoulder or raised ring for the piston to strike. Experience has shown, however, that counterboring a gas-engine cylinder is sometimes likely to do more harm than good, especially if the counterbore extends, as it usually does, to the middle of the outer piston ring, as shown at *d*. In such a case, the outer ring may do very little toward preventing the gas from leaking around the piston.

4. Cylinder With Separate Head.—When the cylinder is provided with a separate removable water-jacketed head, as shown in Fig. 5 (*a*), the head end of the cylinder and the water-jacketed head contain passages, as shown at *a*, *a*, through which the cooling water circulates. The size of these openings in the cylinder is shown more clearly in the enlarged view of the top of the cylinder with the head removed in Fig. 5 (*b*), the water passages being shown at *a*, *a*. The openings in the head and in the head end of the cylinder must match when they are put together, and any gasket placed between them must have holes cut to match these openings. The bolt holes must be so located that the joint may be made tight. Occasionally, the openings are made round, so that a part or all of them may readily be tapped and plugged. Since these passages should be as large as possible, the thickness of the metal on the inside forming the cylinder wall and that on the outside is sometimes made as little, in the case of small engines, as $\frac{1}{4}$ or $\frac{3}{8}$ inch. Under the high pressures developed in the gas-engine cylinder, the strips, shown at *b*, *b*, are so narrow that it is only with difficulty that the joint is made tight at these points. Cylinder heads for small engines are sometimes

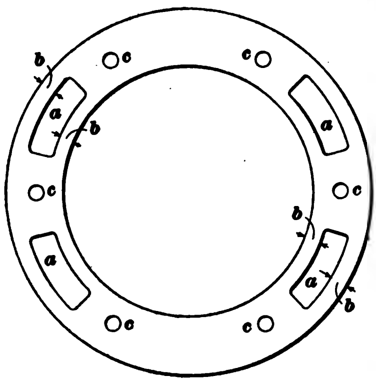


FIG. 5 (*b*)

made so thin that they will spring between the studs shown at *c*, *c*, allowing the gasket, or packing, to be blown out by the pressure; this is due to faulty design. Occasionally, the head and cylinder are put together with a ground joint—that is, no packing or gasket is used between them—but such a joint is difficult to keep in good condition where the head must be removed for inspection or repairs. The difficulty of bringing the surfaces to such a condition that they will not leak is so great that very often a gasket must be used after the head has been removed a few times.

Some manufacturers omit the cored openings for communication between the water-jacket and the head, using an outside connection instead, either cast on as shown in

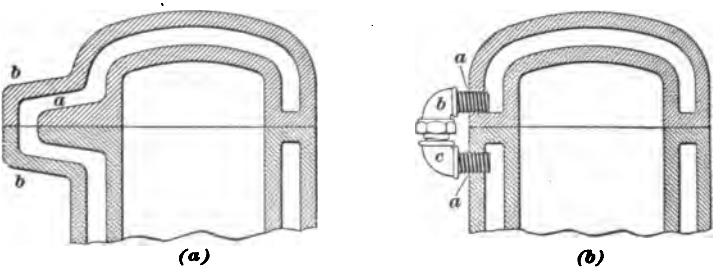


FIG. 6

Fig. 6 (*a*) or connected by means of pipe connections as shown in Fig. 6 (*b*). In Fig. 6 (*a*), the water passage *a* is cored in the lugs *b*, *b*, in the cylinder and head. In Fig. 6 (*b*), the connection is made by means of two short nipples *a*, *a*, a union elbow *b*, and a common elbow *c*.

5. Ports in Two-Cycle Engine Cylinder.—In two-cycle engines, the gas is compressed in the crank-case before being admitted to the cylinder. The usual location of the ports in two-port two-cycle vertical engines having the inlet port on one side and the exhaust port on the opposite side is shown in Fig. 1. The lower edges of both ports are on a level and even with the top of the piston when in its lowest position. Single-cylinder gasoline engines of the marine type are usually set so that the natural pitch of the

engine will cause any gasoline that might enter the cylinder to flow out of the exhaust.

The ports are sometimes, though rarely, located 90° apart on the same level, and sometimes 135° apart, but neither are much used, opposite ports being most common.

Another type of two-port engine is shown in Fig. 7. In this case, a port *a* in the piston registers with the inlet port *b* to the cylinder, the object being to reduce the clearance in the crank-case and thereby increase the compression. The exhaust port is shown at *c*, and the igniter connection at *d*.

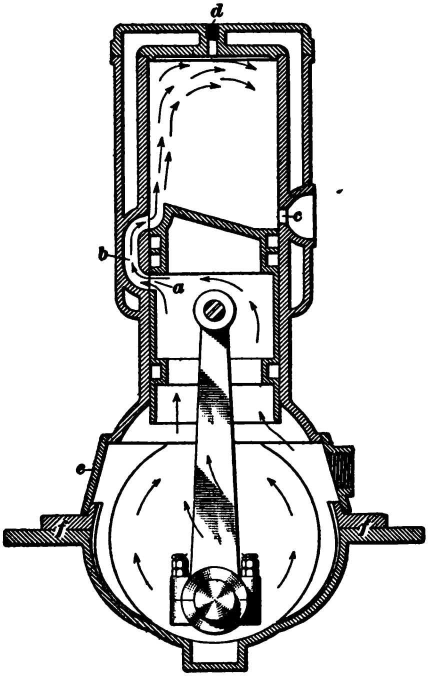


FIG. 7

6. The three-port type of two-cycle engine cylinder differs very little from the two-port type. The usual three-

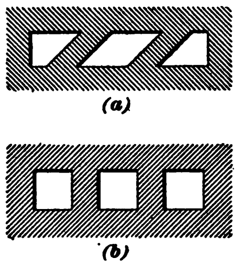


FIG. 8

port arrangement is shown in Fig. 5 (*a*); the exhaust port is shown at *b*, the gas-inlet port at *c* leading into the crank-case, and the transfer port *d* leading from the crank-case into the combustion chamber *f*. In three-port engines, it is customary to place the crank-case inlet directly below the exhaust, in order to utilize a part of the heat of the exhaust in heating the gasoline vapor as it enters the crank-case. The ports are divided so as to prevent the piston rings from

catching in what would otherwise be very long openings. The general form of these ports is shown in Fig. 8 (*a*) and (*b*), the bridges between the openings being diagonal in Fig. 8 (*a*) and vertical in Fig. 8 (*b*). The diagonal form is generally preferred, as it tends to produce more even wear on the piston and rings.

There is another type of two-cycle cylinder construction, shown in Fig. 9, in which the transfer passage *a* from the crank-case to the combustion chamber is carried through the head *b*, and the admission of the charge to the cylinder is controlled by a poppet valve *c*. The igniter connection is shown at *d*. In other respects, the cylinder of this engine resembles very closely that of the engine shown in Fig. 7.

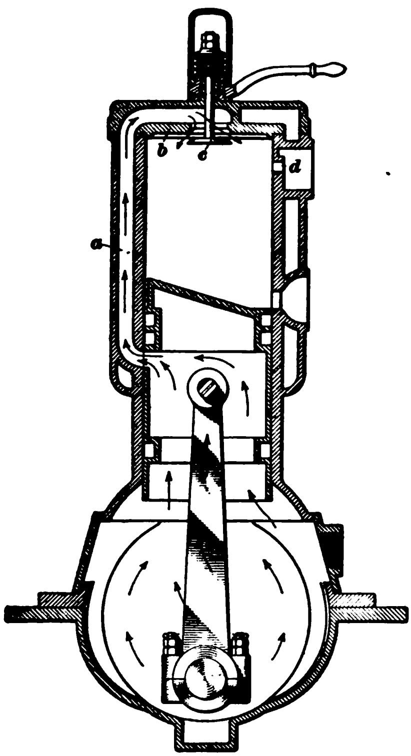


FIG. 9

7. Cylinder of Four-Cycle Engine.—Cylinders of four-cycle automobile and marine engines of the water-cooled type are frequently made as shown in Fig. 10. The inlet valve is shown at *a*, and the exhaust valve at *b*, on the opposite side of the cylinder. In the cylinder head is the compression relief valve *c*, also used for admitting gasoline with which to start the engine. The screwed plugs *d*, *d* over the inlet and exhaust valves make them accessible for repairs. Sometimes the inlet and exhaust valves are placed together on the same side of the

cylinder, both valves being operated mechanically by the same cam-shaft. The cylinder head of the latter form is sometimes cast with separate passages between the valve chambers and combustion chamber, and the whole surrounded with the water-jacket.

Some four-cycle vertical engines are provided with auxiliary exhaust or relief ports that are opened at nearly the end of the down stroke. The purpose of the auxiliary port is to relieve the pressure on the exhaust valve and make its opening much easier. The pressure in a four-cycle cylinder at the time the exhaust valve is opened is frequently as high as 50 or 60 pounds; and, as the exhaust valve is often 3 inches or more in diameter, the power necessary to lift the valve from its seat is considerable. To relieve this pressure, the auxiliary port is provided. In one type of engine, a poppet valve is used in the auxiliary exhaust to prevent exhaust gases from passing through the port into the engine during the suction stroke, when the engine is closely throttled. A marine engine of this type would seldom be throttled to such a point that a valve in the auxiliary exhaust would be necessary.

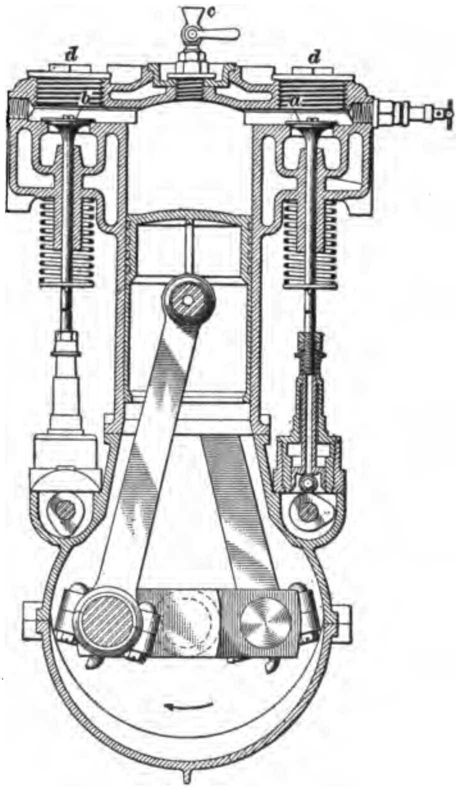


FIG. 10

WATER-JACKETS

8. In order to prevent the high temperature inside the cylinder from burning the lubricating oil and damaging the piston and cylinder, it is necessary to keep them cool by circulating a stream of water around the cylinder, or by some equivalent means. Hence, the **water-jacket** that surrounds the cylinder is one of the important features of the internal-combustion engine. From a scientific point of view, a stream of water circulating around a cylinder in which a flame is burning is very wasteful, but for general use nothing better has yet been found. For small automobile engines, however, it is found possible under certain conditions to substitute a strong current of air that strikes directly on the outer surface of the cylinder.

Great care must be taken to select lubricating oils that will stand even as high temperatures as those reached in the cylinder walls with water cooling. Moreover, difficulty would be found in employing higher temperatures, for the reason that the fresh charges would be likely to ignite from contact with the hot cylinder walls. When such inflammable fuel as gasoline is used, it is necessary, in order to avoid premature explosion when high compression is used, to keep the walls of the combustion chamber, the piston head, and the valves reasonably cool. Unless the engine runs too slowly, it is found that more is gained by the use of fairly high compression than is lost by the more rapid cooling it necessitates.

9. The proper way to reduce as far as possible the loss of heat by the water-jacket is to make the walls of the combustion chamber as small as possible, thus reducing the area of the cooling surface. It will be noted, from the character of the motion imparted to the piston by the crankpin, that near the beginning and end of its stroke the piston is moving very slowly. This slowness of movement is advantageous in a way, especially for a high-speed engine, since it gives the flame a chance to spread before expansion is well under

way. It has the disadvantage, however, in a slow-speed engine, of holding the mass of burning gas in contact with the walls of the combustion chamber for some perceptible time before expansion begins, and a good deal of heat can be lost through the walls in this time. As a highly compressed charge burns faster than one slightly compressed, it follows that high compression is not desirable for a slow-speed engine.

10. Water-jackets that are cast with the cylinder have the disadvantage that they cannot readily be cleaned when scale-deposits accumulate in them. Hence, the water-jackets for some small engines are made of sheet metal, as shown in Fig. 11. The water-jacket, shown at *a* surrounding the

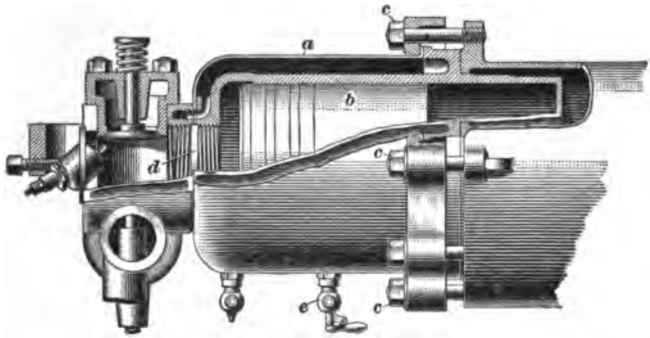


Fig. 11

cylinder *b*, is made of heavy sheet copper held in place, without gaskets, by means of the bolts *c* at one end and the right-and-left nipple *d* at the other end. A compression relief cock *e*, operated by means of a hand wheel on a rod extending outwards from the cock to a point outside the frame, is provided for reducing the compression pressure to facilitate starting. The water-jacket may be drained through a drain cock *f* screwed into a boss brazed to the outside of the jacket. Water-jackets of this type can be removed from the cylinder when it becomes necessary to clean them or when repairs to the cylinder make it desirable. The cylinder shown in Fig. 11 is of the automobile type.

In Fig. 12 is shown the cylinder of a marine engine with separate water-jacket made of bronze. The cylinder with the jacket removed is shown at *a*, the water-jacket at *b*, and the cylinder and water-jacket together at *c*. The surfaces of both cylinder and water-jacket that are to come together are finished, and the water-jacket is slightly heated and forced on

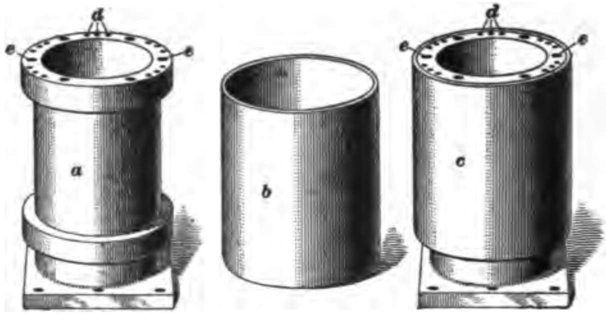


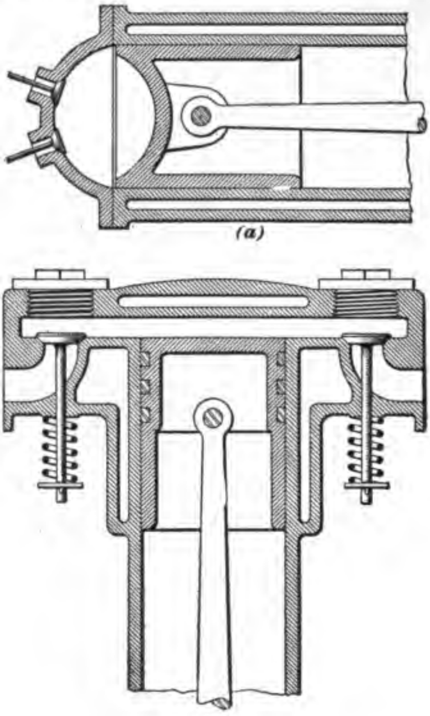
FIG. 12

the cylinder. The small holes shown at *d* in the upper flange of the cylinder are provided for the circulation of the cooling water from the cylinder head to the cylinder. The cylinder and head are held together by means of capscrews or stud bolts, the holes for which are shown at *e*.

COMBUSTION CHAMBER

11. In Fig. 13 (*a*) and (*b*) are shown two very different forms of combustion chamber. The one shown in Fig. 13 (*a*) is made with as small a surface as possible for a given contained volume, even to the extent of making the piston head dished or concaved. More than a slight amount of dish in the piston is not really desirable, for the reason that a flat piston head, having the smallest possible area, absorbs the least heat. The combustion chamber shown in Fig. 13 (*b*) represents the opposite extreme, which is to be commended only under unusual conditions. The valves are carried out in long valve chambers on each side, and although the width of the valve chambers is less than the diameter of the cylinder, they

add very considerably to the total wall area of the combustion chamber. If the compression is low and the speed high, this arrangement is permissible, since the burning gases do not have much time to cool before expansion; but it is always desirable to bring the valves as close to the cylinder as practicable.



(a) (b)

FIG. 13

CRANK-CASES

12. Every gas engine must be provided with some kind of frame or bed for supporting the main bearing and the cylinder. In the four-cycle engine, the frame is usually open in construction, except when the splash system of oiling is employed. In such cases, the moving parts of the engine are partly or wholly enclosed by a casing called a **crank-case.** The name crank-case is, however, more generally applied to the closed base of the two-cycle engine, which is made air-tight in order that the gases can be compressed slightly before being admitted to the combustion chamber. In a four-cycle engine, this arrangement, however, has the disadvantage that, when the hot gases leak past the piston rings into the crank-case, there is a tendency to overheat the bearings and burn the oil, and through imperfect lubrication cause rapid wear of the engine. With an open frame, such a condition would be prevented, as the connections and

bearings may readily be inspected and any wear can be taken up before any great damage has been done. The enclosed crank-case is, however, much cleaner than the open frame.

13. The crank-case should have large easily removable plates or panels, in order that the parts enclosed may be inspected and also, in four-cycle engines, that the hot gases may readily escape. Some engines have handholes covered with plates on both sides of the engine, through which the crankpin connections can be reached. In others, the lower connections are reached by removing the lower half of the crank-case. When the base separates in line with the crank-shaft, the handhole plates are not absolutely necessary, although they furnish easy access to the crank-case to examine connections or to wash out dirty oil or grease. In Fig. 7 is shown a two-cycle engine having a handhole *e*, as well as a crank-case divided along the line *ff*.

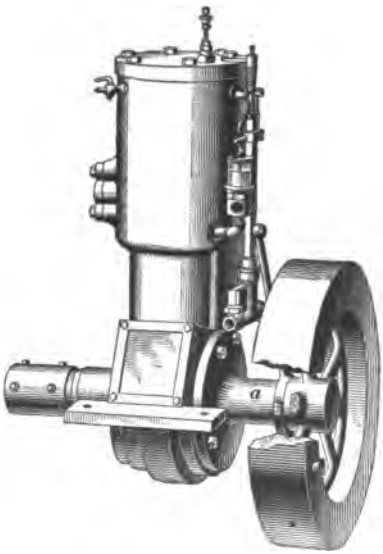


FIG. 14

Some two-cycle engines have the cylinder and crank-case cast in one piece, with separate end-plate bearings bolted to the crank-case to support the crank-shaft, as shown at *a*, Fig. 14; others have their crank-cases parted in line with the center of the crank-shaft. Whatever method is adopted, it is necessary that the center line of the cylinder shall be exactly at right angles to the center line of the crank-shaft. Defective alinement is often found in engines having the cylinder and crank-case cast together, with end plates for crank-shaft bearings.

14. In two-cylinder two-cycle engines, it is important that one crank-case should not leak into the other, else there would be no crank-case compression. Such a condition is not unusual, and in a double-cylinder engine without removable cylinder heads it might be difficult to locate and overcome such troubles. With the heads removed, it can readily be seen, by noting the way that the gas or air enters the combustion chamber through the passover port, whether or not the compression in the crank-case is sufficient.

Occasionally, two-cycle engines are provided with stuffing-boxes on one or both ends of the crank-case bearings, and sometimes special forms of bushings are used with a fair degree of success to prevent leakage; but as yet no device has been designed that will effectually prevent the loss of some of the compression in the crank-case.

In order that the compression may be high, the cubical contents of the space below the piston of a two-cycle engine, when at the end of its expansion stroke, should be as small as possible.

PISTONS

CONSTRUCTION OF PISTONS

15. Most internal-combustion engines are provided with pistons made hollow to receive one end of the connecting-rod, as shown in Fig. 15 (*a*) and (*b*). Such pistons are of what is known as the **trunk type**, so constructed in order to obviate the use of a crosshead and guides and thus make possible a more compact engine. The piston consists of a hollow cylindrical iron casting carefully machined to have a good working fit in the cylinder. Near the head end of the piston, there are three or more grooves *a* in which are placed *piston rings*, which serve to make an air-tight joint between the piston and the wall of the cylinder. The grooves *a* should be made of uniform width and square with the piston, so that the piston rings will not stick in the grooves when it is desired to remove them.

16. The smaller grooves *b*, Fig. 15 (*a*), aid in distributing the lubricating oil to all parts of the cylinder wall, and thus aid in keeping the pressure from blowing past the piston. They also help to carry oil to the piston pin, when the latter is made hollow.

Some pistons have oil grooves of various shapes between the grooves *b* and the piston rings; while others, either with or without oil grooves, have one or two piston rings on the crank end of the piston, as shown in Fig. 15 (*b*). In some instances, the piston is made to taper slightly from the

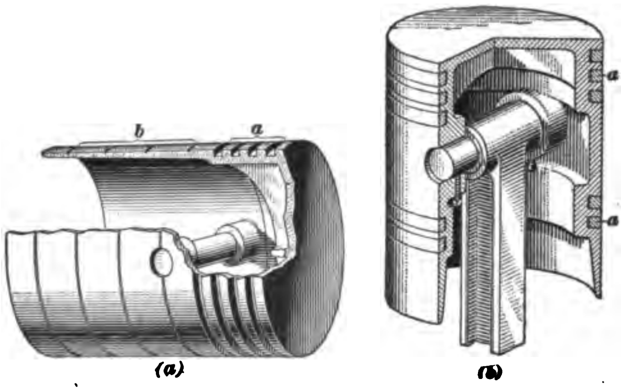


Fig. 15

head to the crank end, to allow for more expansion at the hottest end. Pistons that fit too tightly are liable to become warped or distorted so that they stick in the cylinders, and require considerable power to move them. In such cases, the power of the engine may be increased by reducing slightly the size of the piston.

17. The piston pin is usually set as near to the head end of the piston as possible, leaving just room enough for the piston rings beyond the piston pin. The object of thus locating the piston pin is to make the engine as short as possible, and, in the case of the two-cycle engine, to reduce the size of the crank-case so as to give a higher compression in the latter.

In two-cycle engines, the shape of the top of the piston is very important, particularly if the transfer port is in the side of the cylinder. The part of the piston that projects upwards, as shown at *e*, Fig. 5 (*a*), and that deflects the incoming charge of gas so that it clears the cylinder of the burned gases, is called a **deflector,** or **baffle.** Instead of using such a projection, the piston is in some cases so shaped as to deflect the gases in the same manner; such a piston is shown in Fig. 7.

18. The piston of a two-cycle engine should be longer than the stroke, otherwise the exhaust port would not remain completely covered during the compression stroke and the gas in the crank-case would escape to the atmosphere. The piston must also cover the oil hole of the cylinder lubricator sufficiently to prevent the oil from being blown back through the oil passage and spattered on the sight-feed glass.

In order to have proper lubrication and to keep the exhaust port covered, except when exhausting, the piston should be approximately 25 per cent. longer than the stroke of the engine. It is considered good practice to make the piston .001 inch smaller per inch of diameter than the cylinder. Thus, the piston for a 6-inch cylinder would have a diameter of 5.994 inches.

PISTON RINGS

19. Piston rings for gas and gasoline engines should be made of close-grained gray cast iron of uniform quality. These rings are made with an opening or split, and are of such width and thickness that they can be sprung open enough to slip over the end of the piston and snap into the grooves. Such a ring is sometimes called a **snap ring.** It is practically the only type of piston ring used in gasoline engines, as it seems to answer the requirements better than any other style. The width of the ring should be uniform; it should be free in the groove in the piston and should be in contact with the cylinder for its entire circumference.

Fig. 16 shows the most common forms of snap rings. The one shown in Fig. 16 (*a*) is of uniform cross-section, with the ends lapped at the parting as shown at *a*. There should be more spring in the ends of the ring than at the back *b*; consequently, the ring is frequently made eccentric, as shown in Fig. 16 (*b*). The parting in this case is a diagonal split as shown at *a*, while the parting shown in Fig. 16 (*c*) is a combination of the other two. The diagonal parting is less likely to cut or scratch the cylinder than the others, as no portion of its parting line is parallel with the motion of the piston.

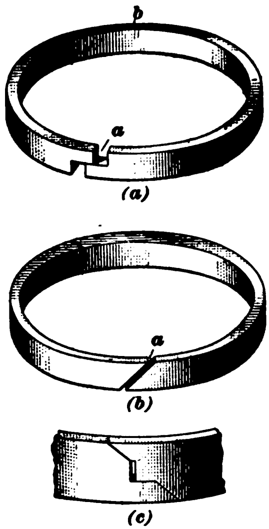


FIG. 16

CONNECTING-RODS

20. Many types of connecting-rods are used on gas engines; three of the more common forms are shown in Fig. 17. The one shown in Fig. 17 (*a*) is rectangular in cross-section. The smaller end *a* is composed of a box containing the brasses *b* that form the piston-pin bearing, and the adjusting wedge *c* through which the wear of the brasses is taken up. The wedge is adjusted by means of the screw *d*, which is locked by a nut when the proper adjustment has been secured. This form of connecting-rod end is known as a *box end.* The large, or crankpin, end, or foot, *e* is attached to the body of the rod by bolts *f*, *f*, which also pass through and hold the brasses *g* and *h*. The outer ends of the bolts are provided with locknuts to prevent the nuts from turning while in service. This form of connecting-rod end is known as the *marine type.*

The connecting-rod shown in Fig. 17 (*b*) is of the I-shaped section, the large end *a* being split at right angles to the rod through the center of the bearing and having a brass lining *b*. The two parts of the bearing are held together

by the bolts *c* and *d*, which pass through the cap *e*. The bolts are provided with locknuts to prevent the nuts from loosening.

The smaller end *f* is made solid, bored out, and a brass bushing pressed into place, as shown at *g*. The connecting-rod shown in Fig. 17 (*c*) is of circular cross-section. Both ends are of the marine type.

Fig. 17 (*d*) shows a hinged end sometimes used on connecting-rods for automobile engines. The end *a* and cap *b*

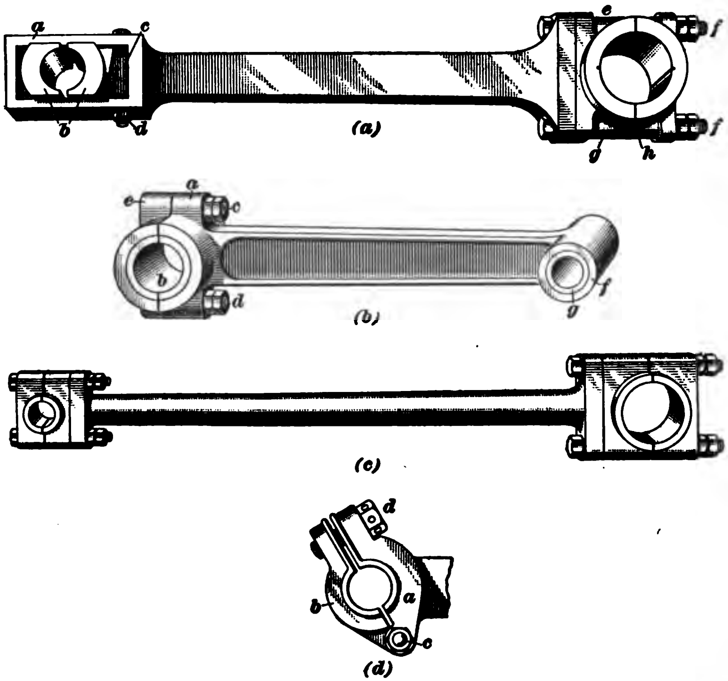


Fig. 17

are hinged at *c*, and a screw *d* is provided to hold the parts together. When the piston end of a connecting-rod is made solid and bored out, it is frequently provided with a bronze bushing. In the more expensive engines, the piston pin and the bushing are often made of case-hardened steel, and both pin and bushing are ground to fit.

21. The length of the connecting-rod depends on the stroke of the engine. It is customary to make the rod about twice the length of the stroke, sometimes a little longer, but more frequently a little shorter. The longer rod decreases the wear of the moving parts, owing to the angular positions of the connecting-rod. The shorter rods, however, permit of a shorter and more compact construction of the whole engine. This is of special advantage in the two-cycle engines where the crank-case is enclosed.

CRANK-SHAFTS

22. Crank-shafts for gas engines are made of steel. They must be strong enough to resist the twisting and bending action to which they are subjected, and the bearing portion must withstand the wear due to continuous rotation at high speed. The type of crank used on single-cylinder gas engines is known as the *center crank*, and has two arms with a crankpin between them. Such a crank is shown in Fig. 18 (*a*). The gear *a* attached to the shaft is the smaller of the pair of two-to-one gears that drive the cam-shaft. The bearings *b* and *c* of the shaft are close to the crank-arms, and the crankpin *d* connects the arms. The two ends of the shaft must be in line with each other, and the crankpin must be parallel with the shaft.

Fig. 18 (*b*) shows a crank-shaft with two center cranks for a two-cylinder engine. The shaft rests in bearings at the points *a*, *b*, and *c*, and the crankpins *d* and *e* are in line with each other and parallel with the bearings. In some crank-shafts for two-cylinder engines, in which the cylinders are opposed horizontally, the cranks are set 180° apart or opposite each other.

Fig. 18 (*c*) shows a crank-shaft for a three-cylinder stationary engine, of the vertical type, with the cranks 120° apart. The cranks are balanced by means of the weights *a*, *a*, *a* attached to the cranks on the sides opposite the crankpins. The arrangement of the cranks shown is considered one of the best for three-cylinder engines, because it so

distributes the turning effect that the engine runs more smoothly.

Fig. 18 (*d*) shows a crank-shaft for a four-cylinder automobile engine, in which all the parts are made as light as

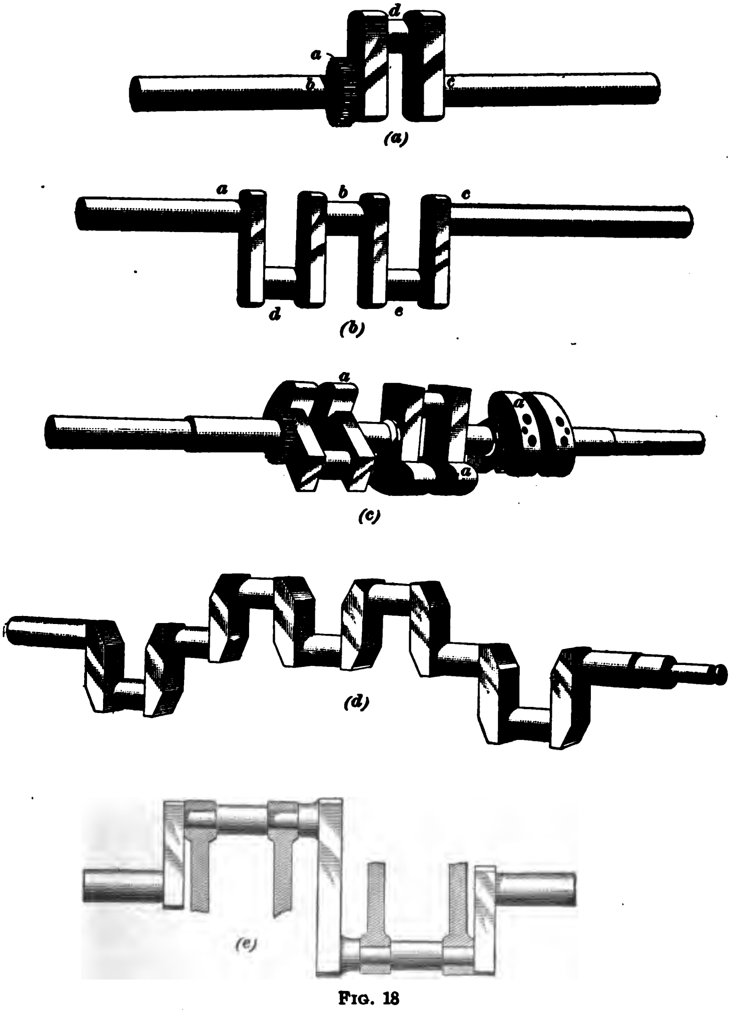


FIG. 18

possible consistent with strength. This is considered the correct arrangement for four-cylinder automobile engines.

A less expensive, but less desirable, crank-shaft is sho Fig. 18 (*e*). In the crank-shaft shown in Fig. 18 (*d*), are five shaft bearings, while in that shown in Fig. 1 there are only two. This, together with the better arr ment of the cranks, makes the engine supplied wit former run with less vibration.

FLYWHEELS

23. In most gas engines, a heavy flywheel is neces but this is especially true of the four-cycle type, as the p receives only one power impulse in each four str Besides this, one of these four strokes is the compre stroke, and the flywheel must store up sufficient ener do the work of compressing the gas. The weight o flywheel depends largely on the use for which the e may be intended. An engine designed to drive a dy must run with very little variation of speed, and th wheel must be heavy. It is not necessary to have so h a flywheel on an engine intended for ordinary shop u for pumping. A flywheel cannot, however, be made h enough to make a single-cylinder engine run without slight variation of speed. Consequently, when even ning is necessary, engines are built with two, three, fo more cylinders, so that the energy that would othe be put into a single-power impulse is divided among three, four, or more cylinders, and each impulse is c spondingly smaller.

Flywheels on marine engines do not need to be as h as those on stationary engines, because speed regulati not necessarily so close. If the engine is intended to b very slowly, the flywheel must be correspondingly he the higher the speed and the larger the number of cylin the smaller and lighter may be the flywheel. Six-cyl marine engines have been built without a flywheel.

The practice of fastening a flywheel to the crank-shaft a tapered key is very satisfactory for small engines, be the flywheel can be easily removed from or fastened t

shaft, either of which may become necessary at almost any time. Another good method of securing the flywheel to the shaft is that of having no hub on the flywheel but of bolting the web of the wheel to a flange turned on the end of the shaft. When the parts are properly machined and fitted, this is also a very satisfactory method, but the bolt holes must correspond exactly, and the flange must be of sufficient diameter to give the necessary support.

VALVES AND VALVE MECHANISM

VALVES

24. Poppet Valves.—A **poppet valve** consists of a disk with a stem at right angles to the plane of the disk. The valve opens in the direction of the axis of the stem. An example of the application of poppet valves to the cylinder of a stationary gas engine is shown in Fig. 19. Two poppet valves are used in this case, one for the admission of the charge and the other for the control of the exhaust. The disks are shown at d and d', and the stems at s and s'. Poppet valves are used very largely in gas-engine practice. They open toward the inside of the cylinder, and are held to their seats by springs. Opening inwards, they have no tendency to leave their seats during the explosion, the pressure in the cylinder helping to keep them on their seats.

The valves required for the four-cycle engine are the exhaust and inlet valves, with occasionally the auxiliary exhaust port, opened by the piston, to relieve the pressure on the exhaust valve. The valves are of various constructions, but all are of the poppet type, sometimes also called the **mushroom type**, shown in Fig. 19. The valve seats with the valve-stem guides may be in the removable heads or in the cylinder casting, or they may be separate castings bolted to the cylinder. The seats of the valves are usually made of cast iron, although where steel cylinders are used the seats are usually of the same material. Nickel steel has

become quite popular for exhaust valves when the hea
stem are made in one piece, also for the heads of bu
valves having the stems made of machinery steel.
claimed that valves made of nickel steel will neither
nor scale from excessive heat. For the same reasons

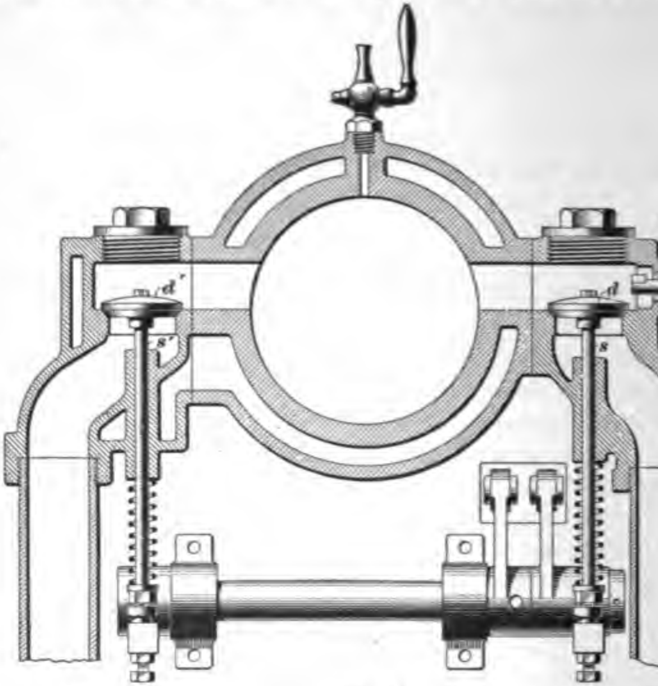


FIG. 19

iron exhaust valves having steel stems are also often
Some trouble has, however, been experienced in se
fastening cast-iron valve disks to steel stems, bu
difficulty is largely overcome by careful machining
brazing.

The valve seats are occasionally flat, though mor
quently they are beveled to an angle of 45°, as sho
Fig. 19; an angle of 30°, however, is sometimes used.
bevel-seat type of valve is kept tight more easily th
flat-seat type and for this reason is generally used.

25. Fig. 20 shows a removable inlet valve and its cage. At *a* is shown the valve; at *b*, the caging, which carries the seat *c* and the guide *d*; and at *e*, a cupped washer, which keeps the pin *f* from coming out and guides the valve spring *g*. The spring bears against a shoulder of the valve-stem guide, around which are holes *h* to provide a passage for the gas. The valve cage is usually placed in a recess in the valve chamber, care being taken to allow sufficient room around the valve *a* to permit a free flow of gas.

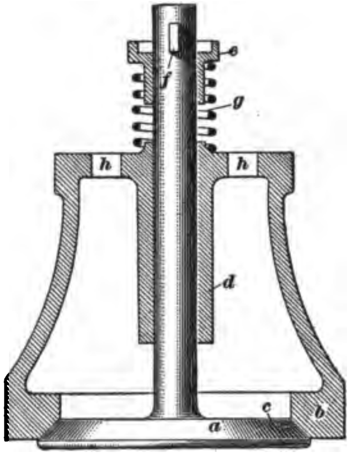


FIG. 20

A common arrangement of an automatic inlet valve is shown in Fig. 21 (*a*). The valve stem *a* works in a guide *b*, which is connected by a three-armed spider to the shoulder cage *c*, against whose base the valve head *d* seats. A gas-tight fit between the valve *d* and its seat is secured by grinding. The shoulder *e* is carefully machined, and fitted against an internal shoulder in the cylinder head, the joint being practically gas-tight. The cage is held in place somewhat as shown in Fig. 21 (*b*), in which the valve *a*, the cage *b*, and the spring *c* differ somewhat from those shown in Fig. 21 (*a*). The cast-iron bell, or elbow, *d* is clamped over the cage to the cylinder head and holds it down by means of the capscrews *e* and *f*, on each end of the yoke *g*, and the setscrew *h* in the middle of the yoke. The opening *i* admits the fuel to the valve and is formed to give a good passage to the incoming mixture. In the center of the valve head, shown in Fig. 21 (*a*), is a slotted boss *f*, to receive a screwdriver for turning the valve for grinding. A thin nut *g*, backed by a cotter pin *h*, retains the spring. As it takes a little time to unscrew this nut, a more common arrangement is the washer and key shown in Fig. 21 (*c*), which is used for both automatic

and mechanically operated inlet and exhaust valves. The end of the spring *i* bears against a cupped washer *j* which is retained by a thin flattened key *k* slipped through a narrow slot in the valve stem *l*. The key is so formed that by compressing the spring slightly it is readily slipped out, but cannot otherwise escape.

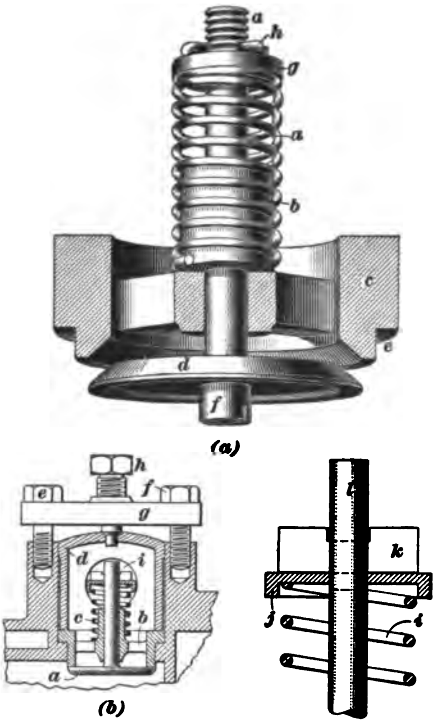


FIG. 21

26. As automatic inlet valves are always made as light as possible, to permit a moderate spring tension to close them, it becomes difficult to arrange a key that will itself be strong enough to stand the continual shocks to which it is subjected, and yet will not be so large as to weaken the valve stem. Inlet-valve stems with keys have but a limited life at best, and for this reason the single-piece valve shown in Fig. 22 has found much favor, as it is little subject to breakage. The valve seat *a* is a simple rim, suitably chamfered at the bottom to fit the beveled face of the valve *b*, and having a circular recess *c* into which fits the cage *d*, split vertically as shown. The portion *e* of the cage forms the valve-steam guide. The head *f*

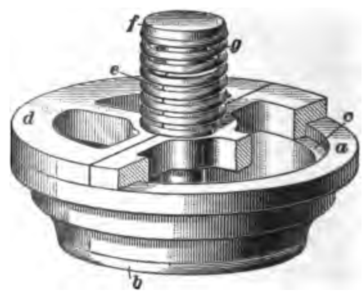


FIG. 22

of the valve stem is made in one piece with the valve, thus dispensing with the usual washer and key. When the parts are put together with the spring *g* in place and the cage *d* in the recess *c*, all the parts are bound together.

VALVE MECHANISM

27. Valve Springs.—All poppet valves, both exhaust and inlet, are held to their seats by means of springs, which in turn are held in place by nuts on the ends of the valve stems, by pins passing through the latter, or by solid heads. When the inlet and exhaust valves are interchangeable, and hence are mechanically operated, the tension of the springs is unimportant as long as it is sufficient to seat the valves. The amount of tension on the springs of automatically opened inlet valves is, on the other hand, an important matter. To get the greatest amount of power from an engine having an automatically operated inlet valve, the spring must be carefully adjusted to insure the required opening of the valve when in operation. In adjusting the tension of the inlet-valve spring, it is necessary to be careful that nothing is accidentally dropped into the cylinder and to make sure that the nut or pin holding the inlet-valve spring does not become loose, especially if the valve is of the inverted type.

28. Valve Action.—There are several methods of operating the valves of automobile and marine engines mechanically, but those most in favor involve the use of cams, while occasionally eccentrics are employed. The cams may operate directly on the valve stems or through bell-cranks or levers. The cam offers possibilities that the eccentric does not; the eccentric, however, insures a positive return of the valve mechanism, while the ordinary cam does not. It is evident, therefore, that an eccentric is better adapted for use on high-speed than on low-speed engines.

In some vertical engines, the cam-shaft, frequently called the **lay**, or **two-to-one shaft**, is not located directly beneath the center of the valve stem, but a little to one side, so that the motion of the cam is vertical instead of horizontal

when it strikes the valve stem, the object being to give a quicker opening and closing to the valve than if the cam-shaft were located directly in line with the axis of the valve. The same object could also be accomplished, but not quite so readily, by using a cam of different shape. Provision is usually made for adjustment, so that the opening and closing of the valve may be regulated to suit the speed conditions.

29. When the inlet and exhaust valves are made interchangeable, they are usually operated by a double set of cams on the same cam-shaft, or by cams on two shafts on opposite sides of the engine, as shown in Fig. 10, the valves being covered by plugs, or held in place by clamps. If the inlet valve is mounted above the exhaust valve, both opening into the same passage, the inlet valve is usually operated automatically, although a rocker-arm actuated through the cam-shaft is sometimes employed to operate the inlet valve mechanically. Poppet valves, such as are shown in Fig. 19, are usually operated by bell-crank levers.

The cam-shafts should be parallel with the crank-shafts if driven by spur gears and provision made for wear, while the cam-shaft should be so set that each cam will perform its proper function at just the right time. It is frequently found that changing the meshing of the teeth of the gears one tooth earlier or later will secure very much better results, but such changing should never be attempted without a clear understanding of the result to be accomplished.

If the cams are fastened to the cam-shafts by tapered pins, the pins should fit tightly and be slightly upset on the smaller end, to prevent them from working out. If held by setscrews, the shafts should be *spotted*, or slightly flattened, under the screws, to prevent the latter from slipping from their proper positions.

30. Spiral Gearing.—A device frequently used for reducing the speed of the cam-shaft on modern gas and gasoline engines of the stationary type is the *spiral gear* shown in Fig. 23. The crank-shaft *c* carries a helical or

spiral gear *G*, which is essentially a short screw having a large number of threads. This gear meshes into the spiral gear *g* on the valve shaft *v*. The number of teeth on this gear is double the number on the gear *G*, so that the shaft *c* makes two revolutions to one of the shaft *v* that it drives. From the valve shaft, the valves themselves are operated by cams.

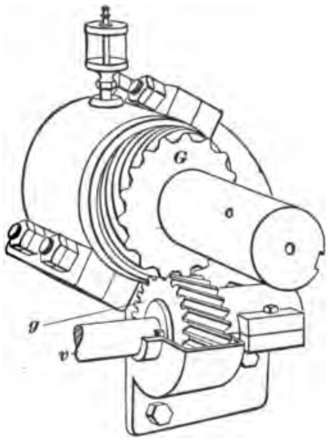


FIG. 23

31. Spur Gearing.—Gears that are in the form of flat disks with teeth on the edges are known as *spur gears*. As these are cheaper than any other form, they are in very common use. An example of the combination of spur gears and eccentrics is shown in Fig. 24. The pinion *g* on the crank-shaft drives the large spur gear *G*, which has twice as many teeth as the pinion *g*, and, consequently, makes one revolution to two of the crank-shaft. The gear *G* drives a short shaft carrying the two eccentrics *e* and *e'*.

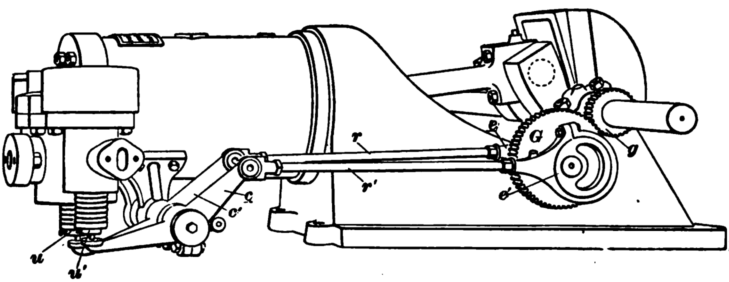


FIG. 24

The motion of the eccentrics causes the two rods *r*, *r'* to reciprocate (move back and forth), and these rods, in their turn, impart motion to the bell-cranks *c*, *c'*. The left-hand ends of these cranks strike the ends *u*, *u'* of the valves, opening each at the proper time.

32. Eccentrics.—Several methods have been d
for avoiding the use of gears altogether. Nearly all,
quite all, of these use an eccentric on the crank-shaft,
attachment which allows the eccentric rod to move th
at every other stroke, only. The valve mechanism,
in Fig. 25, is of this type. Fig. 25 (*a*) shows a plan
device, and Fig. 25 (*b*) a side elevation. The eccent
attached to the crank-shaft *C* and drives the eccentri
by means of the strap *s*. The rod *r* is attached by
joint to a rod *r'*, which slides in the fixed bushing *p'*
cylindrical piece *f* is free to slide a short distance on
has a single-screw thread *x* on its outer surface. This

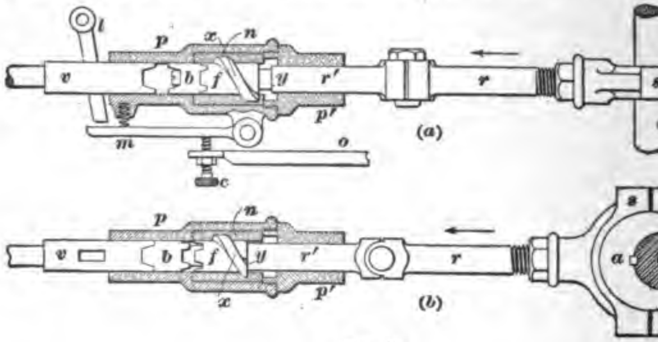


FIG. 25

fits in the corresponding slot in the phosphor-bronze
The left-hand end of *f* has four notches, as shown, wh
corresponding teeth in the right-hand end of the b
The piece *v* is the end of the exhaust-valve stem.

The operation of this mechanism is as follows: The
is free to turn on the rod *r'*, but must move bac
forth with it. The piece *v* contains two notches, wh
corresponding teeth on the left end of *b*, the depth
notches being just equal to the movement of *v*, so that
the teeth on *b* enter the notches in *v*, as shown in Fig.
the valve stem is not moved and the exhaust valve
opened. When the rod *r'* moves in the direction
arrow, the shoulder *y* strikes the piece *f* and pushes
far enough to cause the screw to turn *f* half way a

The shoulder *y* does not, however, strike *f* until the block *b* is clear and the teeth of *f* and *b* are disengaged. But, on the return of *r'*, the teeth of *b* engage with those of *f*, the thread causes *f* to turn, and *b* is compelled to turn with it. The result is that, at each stroke made by *r'* from left to right, the block *b* is given a half turn. If, on the stroke from right to left, the teeth on *b* do not enter the notches in *v*, the valve stem is moved and the exhaust valve is opened. As this happens at every other revolution of the crank-shaft, the valve opens only once in two revolutions.

The rod *o*, Fig. 25 (*a*), is the end of a lever controlled by the governor. If the speed is too high, the governor rod *o* pushes the latch *m* in the way of the lever *l*, so that the exhaust valve cannot close until the speed falls. The speed is adjusted by means of a screw *c*. If a high speed is desired, the screw is drawn back and the rod *o* must move a greater distance before it causes the latch *m* to interfere with *l*.

33. The ratchet eccentric rod shown in Fig. 26 accomplishes the same object in a different way. The eccentric

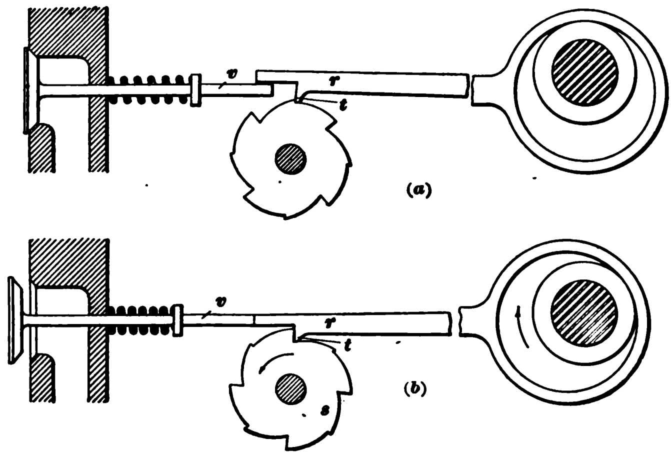


FIG. 26

rod *r*, when moving to the right, slips over the teeth of the ratchet *s*, as shown in the figure, the ratchet being composed

of four deep and four shallow teeth. At each movem
the left, the tooth t engages with one of the teeth
ratchet and pushes it around. If the tooth is a shallo
the rod r does not move the valve stem v, becaus
carried above the end of the stem, as shown in Fig.
When, on the next revolution of the crank-shaf
tooth t falls into one of the deeper notches, as in Fig.
the rod comes in contact with v and the valve is open

34. The Worm-Cam.—Fig. 27 shows a devi
avoiding the use of the eccentric by substituting a p
form of cam, (*a*) being a side, and (*b*) a top, view.
cam a is so made that there is a high portion for abo

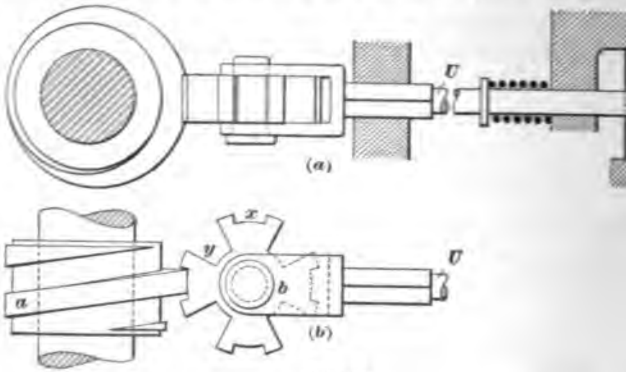
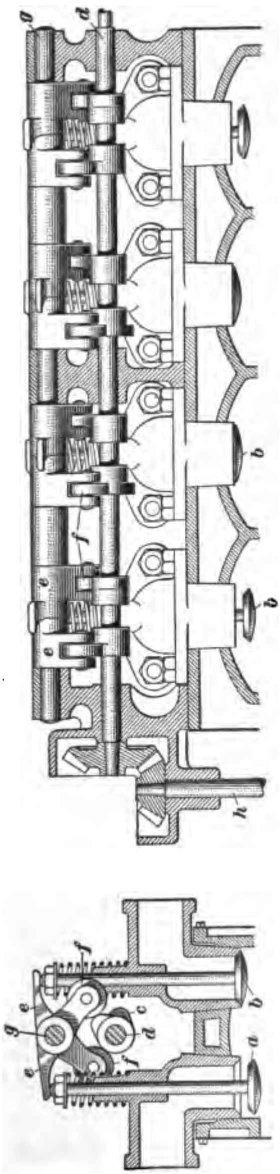


FIG. 27

fourth of its circumference, or, in some cases, it is
form of a screw. The end of the valve stem U ca
worm-gear b having four deep notches y and four s
ones x. The thread of the revolving worm-cam tur
worm-gear b, and the high portion of the cam falls alte
into the notches x and y. As it passes through no
it gives no thrust to the valve stem, because the high
tion of the cam does not reach the bottom of the large
But when it comes in contact with notch x, it gives a
to the valve stem and opens the valve.

35. Bevel Gears and Cams.—The valve-ope
mechanism of a four-cylinder four-cycle engine design



(b)

Fig. 28

(a)

automobile and marine use is shown in Fig. 28, (*a*) being a sectional end view and (*b*) a front view. The inlet and exhaust valves *a* and *b*, Fig. 28 (*a*), are interchangeable and are mechanically operated by means of cams *c* on the cam-shaft *d*. The cams operate the valves through bell-crank levers *e*, provided with steel rollers *f* and mounted on a fulcrum shaft *g* on which they turn. The cam-shaft *d* is driven by means of bevel gears attached to the shaft *h* and meshing with similar gears on the crank- and cam-shafts.

MISCELLANEOUS ENGINE FITTINGS

COMBINED PRIMING AND RELIEF COCKS

36. A cock by means of which the pressure in the cylinder due to compression may be relieved when starting the engine, and which also serves as a priming cock, is shown in Fig. 29. It consists of a circular plug *a* carefully ground to fit the tapering, or conical, socket in which it is turned by means of the handle *b*. The cup *c* is sufficiently large to contain the required amount of gasoline for the priming charge when the engine is to be started.

The plug *a* is held in place by a phosphor-bronze s
placed between two washers *e* and *f*, a pin *g* serving
the whole together. The tension
spring *d* is sufficient to hold th
firmly in position and to take up
thus preventing loss of compress
leakage. The spring also ser
keep the plug tight under heavy
tion. In using this plug, the g
for priming is poured into the
and the cock *a* is turned so
permit the gasoline to flow in
cylinder either before the eng

FIG. 29

started or during the suction stroke. The cock i
left open while the engine is turned over in startin

GASOLINE STRAINERS AND TRAPS

37. To keep out particles of dirt, and particularly
all gasoline should be carefully strained when poure
tanks and when run into carbureters. To accompli
purpose, the funnels used in filling the tanks should b
with fine-wire gauze about one-third the way to the to

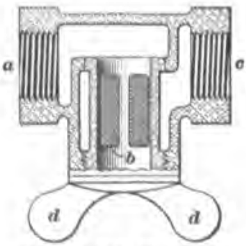


FIG. 30

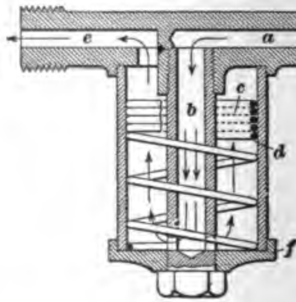


FIG. 31

an additional safeguard, a piece of chamois may b
to prevent water and dirt from passing into the tanks
devices shown in Figs. 30 and 31 are used to stra
gasoline as it flows from the tank to the carburete

should be placed at the lowest part of the gasoline pipe between the tank and the carbureter. They are of comparatively little use unless cleaned out frequently. In the one shown in Fig. 30, the gasoline flowing through the inlet *a* must pass through the strainer *b* and thence to the outlet *c*. Being mounted in a screw-cap *d*, the strainer may readily be removed for cleaning by unscrewing the cap. Fig. 31 shows a strainer in which the gasoline passing through the inlet *a* flows downwards through the center tube *b* and out into the body of the strainer, which serves as a dirt and water trap. The gasoline filters upwards through four gauze strainers *c*, held in place by the spring *d*, and passes to the carbureter through the outlet *e*. The strainer may be cleaned by unscrewing the center tube *b*, the lower end of which is hexagonal and holds the cap *f* of the strainer in place.

CHECK-VALVES

38. Three types of **check-valves** are commonly used in the piping for automobile, marine, and stationary gas and gasoline engines; namely, the *globe-poppet* type, the *swing* type, and the *ball* type, as shown in Fig. 32 (*a*), (*b*), and (*c*). In the check-valve shown in Fig. 32 (*a*), the disk *a* is provided with wings *b* on the bottom and a guide *c* on the top to keep the valve from tilting sidewise and also to prevent its opening wider than necessary. In putting check-valves into piping, it should be noted that the flow must be with the check, and not against it, because the action of a check-valve permits a free flow in one direction but prevents a return of the fluid.

Fig. 32 (*b*) shows what is known as a **swing check-valve,** for use in either a horizontal or a vertical pipe. The valve disk *a* is attached to an arm *b* hinged at *c* and with the seat at *d*. The disk and arm are so connected as to permit a slight movement of the disk so that it will seat properly. The lug *e* on the arm *b* strikes the screw *f* when swung open, thus preventing too large an opening. The screw-cap *g* covers the opening that gives access to the

valve for inspection. The direction of flow of the fluid is indicated by the arrows.

An **angle check-valve** of the ball type, designed to be used in any position, is shown in Fig. 32 (*c*). The fluid enters at *a*, forces the ball *b* to the right against the pressure of the spring *c*, and flows out at *d*. When the fluid ceases to flow, the ball *b* is held in place by the spring *c*, thus preventing

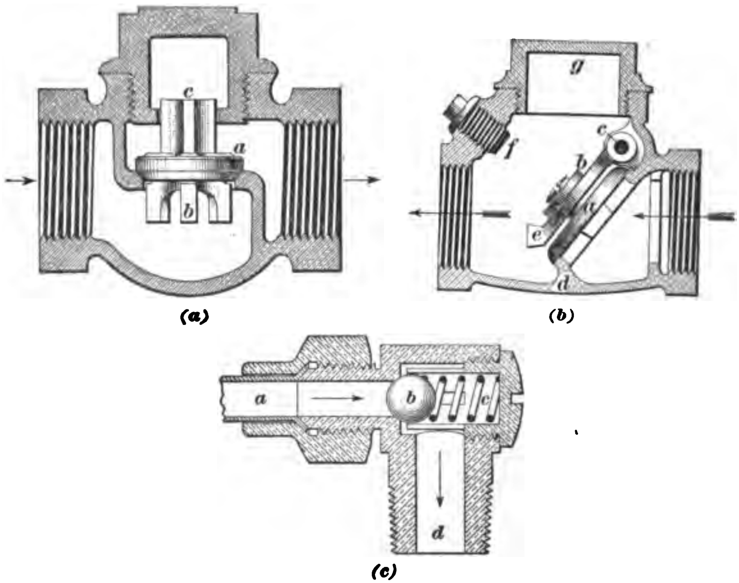


FIG. 32

any flow in the opposite direction. This type of check-valve is largely used in conjunction with the force-feed lubrication of the various parts of engines and connected mechanism in automobiles and motor boats.

39. Fig. 33 illustrates a type of **balanced check-valve**, for use on the supply piping to the crank-case of a two-cycle engine. The gases pass through the valve in the direction of the arrows. When a slight vacuum is produced in the crank-case, the valve disks *a* and *b* are lifted off their seats, and the explosive mixture passes through the

check-valve into the crank-case. As the charge in the crank-case is compressed, the valve disks return to their seats, thus preventing waste through loss of compression. The area of the disk *a* is greater than the area of the disk *b*, so that, when a slight vacuum is produced on the outlet side, the two disks are raised against the spring *c*, thus permitting the gas to pass through. The areas of the two disks are such that the spring need not be very strong. The tension of the spring and lift of the valve disks are adjusted by means of the screw *d* and locknut *e*. The valve disks and spring may be removed for inspection or repairs by unscrewing the cap *f*, which is provided with a hexagonal boss or projection to receive a wrench.

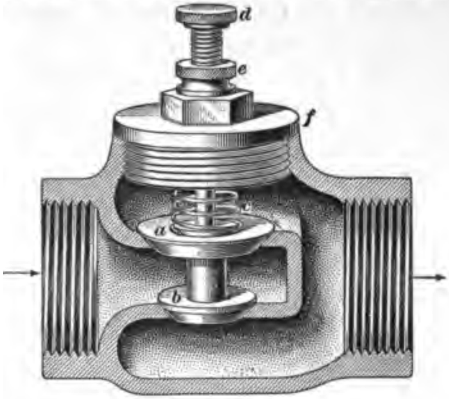


FIG. 33

GASKETS

40. In order to make the joints of a gas engine air-tight, a packing, or **gasket,** is placed between the two parts forming the joint. The materials used in making such gaskets are usually copper, lead, asbestos, brown paper, wire gauze, etc., or combinations of these materials. Gaskets containing rubber should never be used around a gasoline engine or in gasoline-supply piping, because rubber is more or less soluble in gasoline. In the water-supply and discharge piping, rubber gaskets or packing are frequently used, but it is much better to use ground-joint unions, that is, unions in which the joint is made by metal surfaces ground together. This form of joint is also used in gasoline piping, where gaskets of any description are dangerous. The use of a gasket material

composed largely of brass-wire gauze and asbestos is inc ing rapidly. When properly fitted and provided with gra facing, such a gasket will, with care, last a long time. C bined copper and asbestos ring gaskets are also well ada for use in recessed places, under inverted inlet valves, s plugs, valve bonnets, etc. This form of gasket consis compressible, elastic packing encased in soft-rolled co which makes a lasting joint under high pressures temperatures.

BOLTS, SCREWS, STUD BOLTS, AND COTTERS

41. Bolts should be used for fastening the diffe parts of the gas engine together whenever a strong joi desired, unless the construction of the part is such that cannot well be done. This is particularly true for eng used about salt water, where all iron parts rust very rap It is much easier to split and remove a rusted nut fr bolt than to drill out the rusted end of a capscrew that been twisted off when trying to remove it from the part which it was screwed.

Capscrews and **tap bolts** have a thread on one end a hexagonal head on the other. They are sometimes where it is difficult or impossible to use a bolt and a Where two parts are to be fastened to a capscrew, a ho drilled through one and a smaller hole drilled and ta into the other. The parts are put together, and the screw passed through the larger hole and screwed into tapped part.

Setscrews are used for fastening collars or coupling shafts, or for fastening other temporary connections. heads are often square, but are sometimes of other sha The points may be conical, flat, ball-shaped, or cup-sha so that when screwed into place they prevent the parts slipping. The shaft should have a small depression w the setscrew strikes it, so that the setscrew will hold b without causing a burr to be formed on the shaft. heads of all projecting screws in revolving machinery sh be covered by a guard, so as to prevent the possibilit

accidents to any person through catching the clothing on such projections while the machinery is in motion.

Stud bolts are rods of wrought iron or steel with threads cut on both ends; one end is screwed permanently into some part of the engine to hold in place another part—such as, for example, a brace, a cylinder head, or a valve cage—by means of a nut screwed on the other end of the stud bolt. As the parts into which these stud bolts fit are frequently made of cast iron, they sometimes rust solid; but constant removal of the loose parts tends to destroy the threads on the free ends of the stud bolts and hence to produce trouble from leakage. They should be used in preference to capscrews wherever possible.

Spring cotters, or **split pins,** are necessary on bolt or stud nuts to prevent them from jarring loose and from working off entirely. They should be used wherever loose bolts or nuts are liable to prove harmful.

COLLARS

42. **Collars** are generally used to prevent or limit endwise motion of revolving or reciprocating parts. They are either solid or split. Solid collars may be held in position by setscrews, taper pins, or other means, or they may be used loosely on shafts to keep other parts at a distance. Split collars are made in halves and are held together by pins or screws, as shown in Fig. 34. While they are not so strong as the solid pattern, they are frequently very convenient and often used in gas-engine practice. The split collar has the advantage over the solid form in that it can be put into place anywhere in a space equal to twice its width, while the solid form must be slipped over the end of the part on which it is to be fastened.

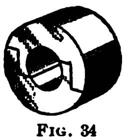


FIG. 34

SPRINGS

43. While in stationary and automobile practice s
used almost exclusively for engine springs, in marine
tice it is necessary to use bronze or German silver wh
possible, on account of the presence of salt in the
phere. Valve springs, however, are usually made of
either natural or tempered, the former being wound
and the latter being tempered after they are formed. N
springs have the disadvantage of becoming set if sub
to hard usage, while tempered springs are liable to br

Almost every kind and form of spring known is us
gas engines, but the helical spring, or spring wound
form of a screw thread, is used more often than any
Occasionally, the springs on inlet and exhaust valv
made up in the shape of a cone. Frequently, tor
springs, or springs constructed to resist torsion, or tw
are used, and occasionally flat springs. The flat spri
perhaps, more likely to give poor results than any
type, and for this reason is less often found in practic
any other.

GAS-ENGINE LUBRICATION AND BEARINGS

LUBRICATION AND LUBRICATORS

SYSTEMS OF LUBRICATION

1. Introduction.—Lubrication consists in introducing some substance, either liquid or solid, between two rubbing surfaces, to reduce the friction and the wear that otherwise would occur. No matter how smooth a metallic surface may appear to the sight or to the touch, it is, in reality, covered with very minute projections, or ridges and hollows. These are readily seen under a microscope. Hence, when two clean metallic surfaces are placed together, and motion is imparted to one or both of them, so as to cause one to slide or roll upon the other, these little ridges engage one another, or interlock, with the result that some of the projections are torn loose from each piece. It is this tearing away or abrading of the metal that causes wear, and the resistance thus offered is known as *friction*.

When a lubricating substance, such as oil, grease, or graphite, is put between the two surfaces, it fills the little hollows and forms a thin film or layer that prevents the metals from actually touching each other except at the points of the highest ridges. As a result there is less wear, since a smaller number of ridges are torn loose, and this means less friction also.

2. The essential principles of lubrication are the same in gas engines of the automobile, marine and stationary types. The methods of carrying the lubricant to the rubbing surfaces, however, may differ in the three types, owing to the different arrangement of parts and auxiliaries. In all that follows, therefore, the statements concerning lubrication will apply to all types of gas engines, for whatever service they are used, unless specific reference is made to a particular class of engine.

3. When a gas engine comes from the manufacturers, it may be supposed that the cylinder lubricator has been adjusted to feed the proper amount of oil; if this has not been done, the instruction book furnished by the makers will state the rate at which the oil should be fed, which will usually be from five to ten drops per minute, depending on the average speed of the engine and on the quality of the oil. If the oil is light or thin, more of it must be used than of a heavy oil, to accomplish the same result, since the light oil is more easily decomposed by the heat in the cylinder than is the heavy oil. The object is to feed enough oil to insure perfect freedom of running and little wear of the piston and rings. At the same time, it is well to avoid the use of more oil than is necessary, as this will result in the formation of carbon deposits from the burned oil, and a consequent tendency to preignition, clogging of the valves, sooting of the spark plugs, etc. In any case, only a high grade of mineral cylinder oil should be used, as the troubles that follow the use of an inferior oil will much more than offset the slight saving in cost.

4. Gravity System.—The simplest system of lubrication for the gas engine is that in which the common gravity sight-feed oil cup is so formed that the drops of oil delivered from it to the bearing may be plainly seen as they fall, thus making it easy to regulate the rate of feed. This form of lubricator is at present used quite largely on stationary engines, but only occasionally on automobile engines, and

then only on some single-cylinder horizontal engines. It is too uncertain in its action and requires too frequent adjustment to make it a satisfactory device for automobile service, especially when the engine has more than one cylinder. The same objections hold good with regard to lubrication by means of wick-feed oil cups, in which a wick is used to carry the oil from the cup to the bearing. Wick-feed oil cups were used in some of the early types of automobile engines, but have gone out of use, except for minor bearings, such as those on the cam shaft, where these are not oiled from the interior of the crank-case.

5. **Splash System.**—In some engines, the crank-case is completely closed, and a quantity of lubricating oil is poured into the lower part of the case. At each revolution of the crank the end of the connecting-rod dips into the oil, splashing it about and thus lubricating the cylinder and bearings of the engine. This method of lubrication is termed the **splash system.** In a number of engines the splash system of lubrication is still relied on for the oiling of the cylinders, but it has the disadvantage that the amount of oil thrown depends largely on the speed of the engine, and also on the degree of care exercised to keep a constant oil level in the crank-case. Although this system of lubrication has been found exceedingly satisfactory as regards the main shaft, crankpins, etc., the sensitiveness of the cylinders to over-lubrication or under-lubrication has caused most makers and users to prefer separate cylinder lubrication. In the majority of automobile engines, each cylinder is fed with oil by an independent pipe from an oil reservoir, located on the dashboard or anywhere else near the engine. Oil is supplied, usually by a hand pump, to the crank-case at intervals. Sometimes, however, the main-shaft bearings are oiled by individual oil wells, with oil rings or chains running over the shaft, and these oil wells are supplied with oil either at intervals by hand, or regularly from an automatic oiler. In this case, the crankpins are commonly supplied

with oil by some centrifugal device, the oil being pumped through a pipe and caught by a centrifugal oil-catching ring attached to the crank, and conveyed thence through holes to the crankpin.

BEARING LUBRICATION

6. Plain Lubricator.—A **plain lubricator** is the simplest form of device for automatic lubrication; it generally

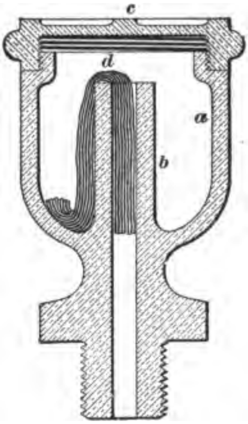


FIG. 1

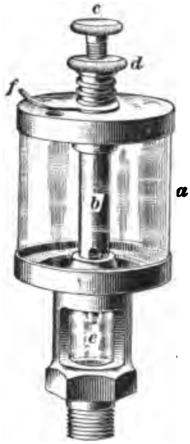


FIG. 2

takes the form shown in Fig. 1. It consists of a cup *a* fitted with a central tube *b* and a removable cover *c*. The oil contained in the cup *a* is led into the central tube by capillary attraction, a few strands of lamp wick, shown at *d*, carrying the oil over. The advantage of this oiling device is its simplicity; the disadvantages are its unreliability and its lack of adjustment of the oil feed. The latter can be adjusted to some degree by changing the number of strands of lamp wick; as the flow of oil is not in plain sight, however, there is always some doubt about the action of the lubricator.

7. Sight-Feed Bearing Lubricator.—A **sight-feed bearing lubricator** has, as the name implies, the oil feed in plain sight. The oil is generally fed by gravity, flowing

through an annular opening in the base of the lubricator. The general appearance of this device is shown in Fig. 2. It consists of a glass oil reservoir *a* having a central tube *b* with a valve seat at its lower end and inside of it. A valve controlled by the screw *c*, which can be locked in any position by the locknut *d*, serves to regulate the flow of the oil. The oil enters through the hole shown in the lower end of the tube *b*. The drops of oil issuing from the tube *b* show plainly in the sight-feed glass *e*. The upper cover has a hole in it, through which the reservoir is filled; a movable cover *f* serves to keep out the dust.

8. Main-Bearing Lubricators.—A bearing of the ring-oiled type is illustrated in Fig. 3 (*a*) and (*b*), the former show-

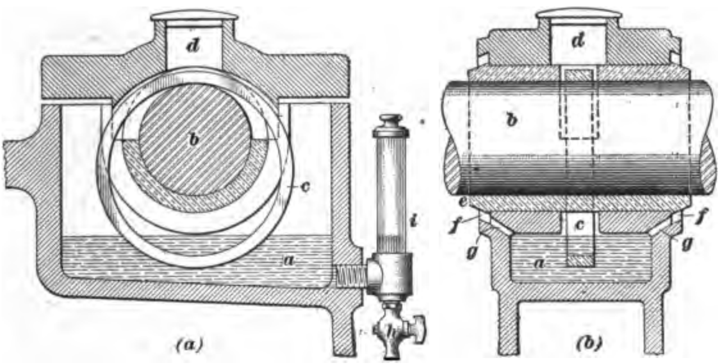


FIG. 3

ing a section at right angles to the shaft, and the latter a section through the axis of the shaft. The oil is contained in a reservoir *a*, and is carried to the crank-shaft journal *b* by the ring *c*, resting upon the journal and revolved slowly as the shaft revolves. Oil is supplied to the reservoir through the cup *d*. After leaving the surface of the journal, the oil flows down the end surface of the bushing *e* into the circular grooves *f*, and through the ports *g* back into the reservoir *a*. When the oil becomes unfit for further use, the reservoir is drained through the cock *h*. A glass gauge *i* indicates the amount of oil contained in the oil chamber.

9. Crankpin Lubricators.—The crankpin is lubricated by attachments of various kinds for conveying the oil from a

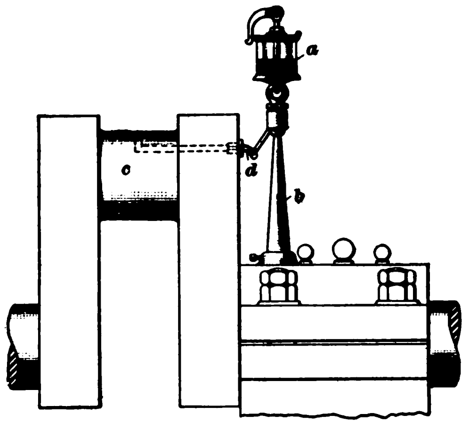


FIG. 4

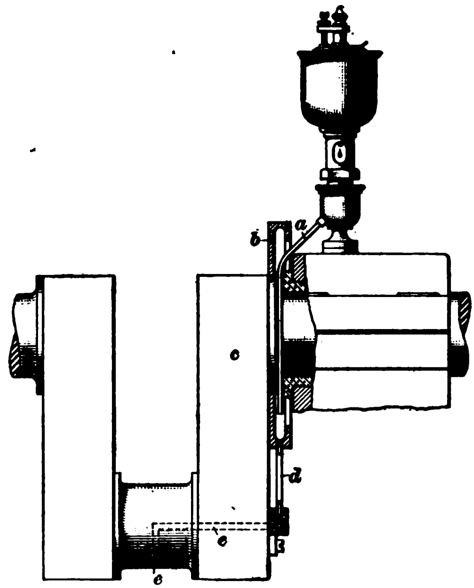


FIG. 5

stationary sight-feed lubricator to the pin. One form of such a lubricating device is shown in Fig. 4. The lubricator *a* may

be mounted either upon a pedestal *b*, provided for this purpose, or upon the crank-guard, and the oil supplied to the crankpin *c* by means of a wiper *d* attached to the side of the crank. The oil may also, as shown in Fig. 5, be conveyed by a tube *a* to a centrifugal oil ring *b* screwed to the cheek of the crank *c* and communicating with the crankpin through a pipe *d* and holes *e*, *e*, drilled into the pin.

CONTINUOUS-FEED LUBRICATION

10. Classification of Continuous-Feed Lubricators. The methods of feeding oil continuously to the cylinders of automobile engines, and sometimes to the main bearings also, may be divided into three principal systems, as follows:

1. The oil is drawn from the tank by a single force pump, and is delivered to as many oil pipes as there are cylinders or bearings to be supplied. The oil passes through individual sight feeds on its way from the pump to the pipes, and these sight feeds may be adjusted by means of valves, so as to regulate the flow of oil to the pipes. This system, which is not extensively used, has the objection that, if the engine by any chance runs unduly fast for a short time, the oil may be pumped faster than it can escape through the regulating valves, and may burst the pipes or break the pump. The likelihood of such an accident is lessened by providing a spring-closed relief valve, which opens and allows the oil to return to the tank when the pressure exceeds a given limit, but this method is not always reliable.

2. The oil tank is located either on the dashboard or lower, as may be convenient, and a pipe connects it with the exhaust pipe of the engine, so that the oil is under a pressure that is limited by a spring-closed escape valve in the pipe connecting with the exhaust. This permits the exhaust gases to escape when the pressure exceeds a given amount, thus maintaining a constant oil pressure. This pressure is sufficient to lift the oil to a row of individual sight feeds on the dashboard, from which it is carried by pipes to the cylinders, and sometimes to the bearings also. As the pressure in the oil

tank is expended in lifting the oil and forcing it through the adjustable sight feeds, it follows that this is practically a gravity feed from the dashboard to the engine.

3. A series of small, independent plunger pumps takes the oil from a common tank, each pump furnishing oil to a different cylinder or bearing. This arrangement secures the nearest approach to a positive oil feed that has been obtained. If the check-valves are tight, this system will give an actually positive oil feed, except in cold weather, when, because of the sluggishness of the oil, the pump barrels may not fill completely with lubricant on the suction stroke. Whatever oil does get into the pump barrel, however, is forced out to the bearings.

11. The Exhaust-Pressure Lubricator.—An exhaust-pressure lubricator that belongs to the second class mentioned is illustrated in Fig. 6. It consists of an oil tank *a*, with several outlets *b*, *b*, four being shown, each leading through an adjustable sight feed *c*, *c*, and each outlet arranged so that it may be shut off at will. The oil tank is mounted on the dashboard, and a gauge-glass *d* in the left-hand side indicates the height of the oil. The oil is introduced through the filling plug *e*, and connection with the exhaust pipe is made at *f*. The tank is filled by forcing oil from an auxiliary tank into it through the central bottom connection *g* and the cock *h*, which is at other times closed.

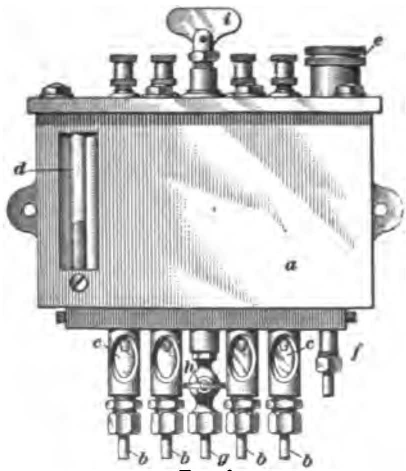
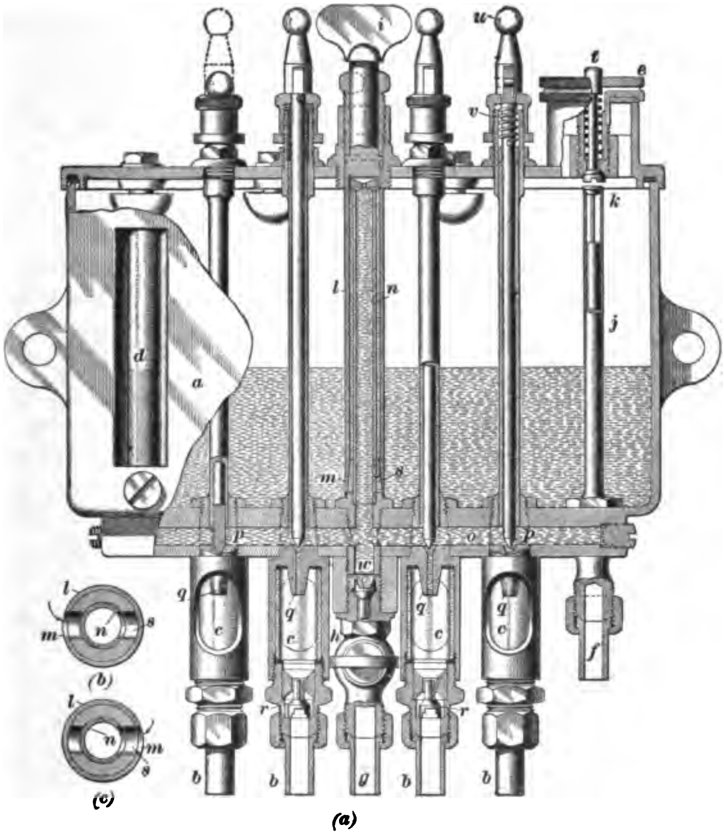


FIG. 6

12. The lubricator just described is so arranged that it may be used for gravity feed, in case of failure of the

exhaust pressure, by simply giving a half turn to the flat thumbscrew *i* at the top. When this is done, however, the sight feeds must be readjusted, on account of the loss of pressure. A sectional view of this lubricator, with the same reference letters, is given in Fig. 7 (*a*). From this figure it will



(*a*)

Fig. 7

be seen that the connection *f* is carried up into a standpipe *j* terminating in a check-valve *k* at the top of the reservoir, from which the exhaust gases escape into the space above the oil. The flattened thumbscrew *i* is connected to a tube *l*, which has at its lower end a bearing that is

practically oil-tight, and has also an opening *m* close to that end. When *i* is set, as shown, for pressure feed, the oil is forced by the exhaust pressure through the opening *m*, through the annular space between the tubes *l* and *n*, and over the top of *n*, through which it passes downwards into the drilled passage *o*, which communicates, through the needle valves *p*, *p*, with all the sight-feed pipes *q*, *q*. After passing through the sight feeds, the oil passes through the check-valves *r*, *r* immediately below them, so that it cannot be forced back by any accidental pressure that may occur in the oil pipes from leakage of the cylinder gases past the piston rings.

13. If it is desired to change the lubricator to gravity feed, this is done by giving *i* a half turn, thus bringing the opening *m* into communication with the opening *s*—which at other times is closed—so that the oil will pass directly from the reservoir into the passage *o*. The two positions of the tube *l* are shown in the small sectional details in Fig. 7 (*b*) and (*c*). The filling plug *e*, which screws down air-tight, is provided with a vent check-valve connecting with the stem *t*. By pushing down this stem, the check-valve is opened and the compressed gas in the reservoir allowed to escape, thus stopping the feeding of the oil, since it cannot then rise to the top of *n*. This is always done, on stopping the engine, to prevent flooding the cylinders or crank-case with oil. The needle valves are opened for feeding by turning the cam-pieces *u* to the vertical position shown. When they are turned horizontally, the needle valves are allowed to seat, thus closing the escape of oil through the tube *q*. The needle valves are adjusted to the rate of feed desired by screwing the caps *v* up or down, the opening being increased by screwing them upwards. If an auxiliary oil reservoir is provided, as is very often done, the oil is pumped from it to the oil tank by hand, through the connection *g* and the plug-valve *h*, the oil so forced being prevented from returning by the check-valve *w* immediately above *h*.

14. Independent Pump System.—A cross-section of an independent pump lubricator is shown in Fig. 8. The

grooved pulley *a* is driven by a belt from any convenient shaft connected with the engine, and turns the worm *b* and worm-wheel *c*, the latter being mounted on the shaft *d*. Secured to this shaft are eccentrics *e*, whose number is

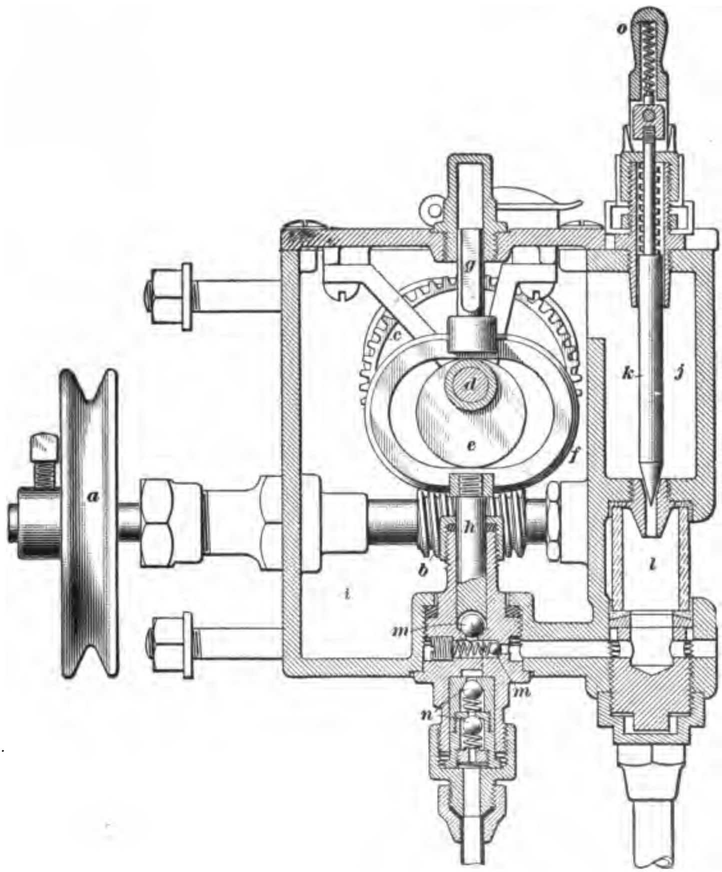


FIG. 8

one greater than the number of bearings to be supplied. These eccentrics work in oval-shaped yokes *f* that are guided by the square stems *g* above, which prevent the yokes from turning, and are connected below to the pump plungers *h*. One of these plungers, not shown, has a cross-section equal to

all the others combined, and lifts the oil from the main reservoir *i* to the auxiliary reservoir, or oil space *j*. This oil space is separated from the chamber *i* by a partition, and if more oil is supplied to the oil space than the bearings take, it overflows into the chamber *i*. From the reservoir *j*, the oil flows down past the adjustable needle valves *k*, one for each bearing supplied, to and through the sight feeds *l*, and then to each pump barrel through the two ball check-valves *m*, *m*, the first a very small one working horizontally and closed by a spring, and the second working vertically and located directly under the plunger *h*.

15. On the down stroke of the plunger, the oil passes out through a passage shown by the dotted lines, and through the two small check-valves *n*, *n*, each closed by a spring. The object of using two check-valves instead of one, both before and after the pump is reached, is to maintain the action of the pump, even if one valve happens to be put out of action by a particle of foreign matter. In case this occurs, the other check-valve will continue to act until the particle has been dislodged and passed on with the oil.

The oil feeds are adjusted by the needle valves *k*, and the effect of this is that the oil passing through the sight feeds *l* is constantly under suction, so that the pumps are able to draw less than a chamberful of oil at each stroke. This prevents any accumulation of oil in the sight feeds. The oil feed may be shut off from any bearing at will, independently of the rest, by turning the cam-lever *o* into the horizontal position, thus closing the needle valve connected to it. Owing to the great reduction of speed produced by the use of the worm *b*, the action of the pump is very slow. It is, however, proportional to the speed of the engine, and in this respect the mechanical lubricator has an important advantage over the exhaust-pressure lubricator, since the average requirement of oil is roughly proportional to the engine speed.

16. Another individual pump lubricator, which has no check-valves or stuffingboxes, and consequently is not liable

to be stopped owing to leakage of these parts, is shown in Fig. 9. The plungers are operated by eccentrics set obliquely on their shaft, so that each plunger is rotated through a certain angle near the top and bottom of its stroke. The plungers are grooved in such a manner as to act as

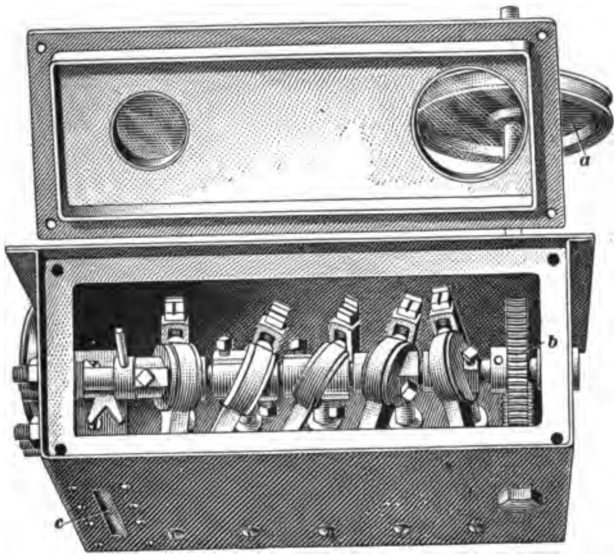


FIG. 9

valves. The lubricator is operated by a round belt over the grooved pulley *a*, which turns a worm meshing with the worm-wheel *b* on the shaft carrying the eccentrics. A gauge-glass *c*, at the front of the case, indicates the height of the oil.

17. The pumps, which are immersed in the oil, are of the same general construction as the one shown in Fig. 10. The oil enters at *a* and passes out to the oil pipe connected at *b*. The pump plunger has a vertical groove *c* that is so located as to be in communication with *a* when the plunger is making its up, or suction, stroke, and is turned to communicate with *b* when the plunger is going down. The latter is the position

shown. By making the plunger a true fit in the pump barrel, and by extending the barrel considerably above the intake and the outlet, the leakage of oil is reduced to a minimum. The stroke of the plunger is adjusted by making the eccentric in two parts, *d* and *e*, which are really two eccentrics, the eccentric *d* being held on the shaft by a setscrew *f*, and the eccentric *e* being held from rotating on *d* by another setscrew *g*. These eccentrics may be turned relatively to each other to give them an effective net throw of anything from zero to the combined throw of both. If desired, the pumps may deliver through several sight feeds, through which the rate of flow of oil may be watched.

FIG. 10

18. Precision Oiler. Another mechanical oiler known as a **precision oiler,** that can be made to feed as many bearings as desired is shown in section in Fig. 11. Its special feature is that it has no valves, check-valves, or stuffingboxes, and yet can be kept tight. Its principle of operation is as follows: The vertical shaft *a* is driven positively from the engine by a mechanism, not shown, on top of the case. There are as many of these shafts as there are separate bearings to feed. The worm on the base of this shaft rotates the wheel *b* in the direction of the arrow. On *b* are two cams: one, *c*, is heart-shaped and works in the rocking fork *d*; the other, *e*, raises the lever *f* and lets it return under the pressure of the spring *g*. The fork *d* is supported

on trunnions at *h*, and moves with the pump barrel *i*, whose base forms the segment of a cylinder, as shown. The plunger *j* has a slotted head, in which the lever *f* works with some lost motion. In the figure, the cam *e* is about to lift *f*, raising the plunger *j* with it, while the cam *c* is imparting no motion to *d*; thus *j* draws oil into *i* through the intake shown at *k*. Presently, while the cam *e* still holds *f*, the cam *c* rocks *d* and *i* until the plunger is opposite the delivery port *n*. Then *e*

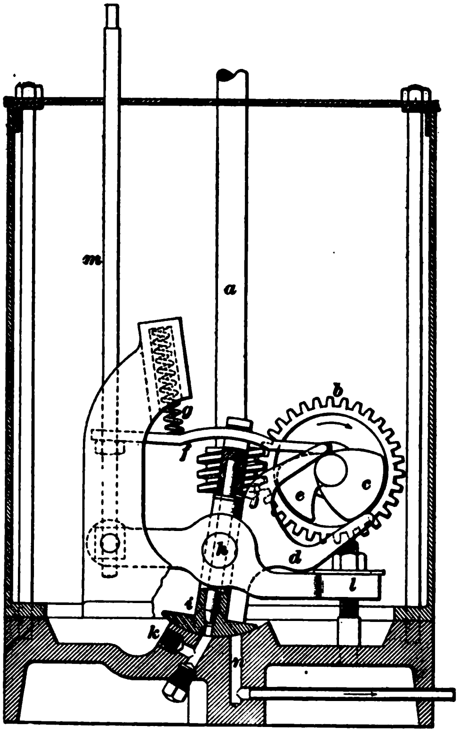


FIG. 11

releases *f*, while *c* holds *d* stationary, and the downward stroke of *j* discharges the oil. This arrangement avoids breakage, in case the delivery pipe is choked. The stiffness of the spring, however, is sufficient to overcome any accidental obstruction. Next *d* and *i* are rocked back to the intake position, and the process is repeated.

The end bearing of the trunnion, instead of being fixed, is carried in the piece *l*, which can be adjusted to take up wear in the base of *i* and its seat. Provision is made for regulating the stroke of *j* by turning the stem *m*, which screws up or down in a nut at the bottom, so that the left end of *f* is raised or lowered, permitting a variation of motion of *f* in the head of *j* on the lift of the cam. It will be noticed that *j* cannot come in contact with the valve seat, the lower end of the barrel *i* being tapered to act as a stop.

19. Marine Lubricators.—There is no type of engine that needs more careful attention in the way of lubrication than the gas engine. To meet the requirements, many special devices are on the market, and those used in marine practice are without exception of the gravity-feed type; while in automobiles it has been found in many cases absolutely essential to use positive-feed oilers or lubricators. Sight-feed oil cups and grease cups of nearly every description may be found on marine gas engines, and they all do their work fairly well. Lubrication is also sometimes accomplished by the splash system. However, the cylinder lubricator is the only one that varies sufficiently from the ordinary types to require explanation here. Without exception, cylinder lubricators are of the sight-feed type, so that each drop may be seen as it is fed to the cylinder. Some are made of metal, while others have glass bodies. Metal bodies do not show the amount of oil left in them, while the glass is liable to fracture. In the former case, a scored cylinder is liable to result; while, in the second, the lubricator would be out of service until the glass was replaced.

20. Fig. 12 shows a very good form of single-feed cylinder lubricator. In case of a strong back pressure from the cylinder, the brass ball *a* will close it off; while, if the pressure is not sufficient to lift the ball, it will be taken care of by the tube *b*, which extends above the surface of the oil, permitting the pressure to be equalized. The lever *c* when

down closes the needle valve that regulates the feed, and the cup can easily be filled by sliding the cover *d* to one side. When the lever *c* is in a vertical position, the cup is feeding; the feed extending well into the large sight-feed glass *e* prevents the oil from adhering to or clouding the glass. The amount of feed is regulated by the thumb nut *f*, held in place by the spring *g*.

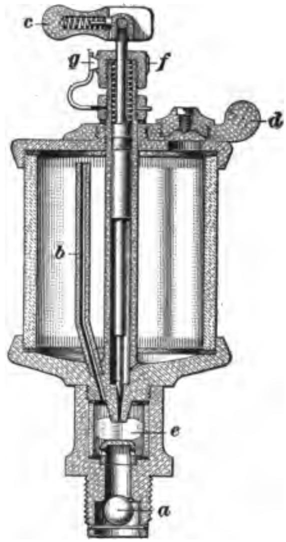


FIG. 12

21. Fig. 13 shows the pressure-type multiple oiler, a type that is becoming very popular for marine use, and that can be arranged with a partition and two filling valves, so that engine oil may be fed through some of the oil ducts and cylinder oil through the others. Large glass ends *a* show the amount of oil in the reservoir at all times. The amount of oil going to each bearing may be noted at the sight-feed glasses *b*, *b*, and regulated by the

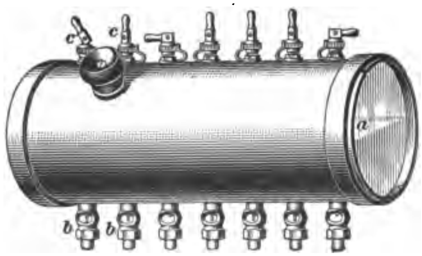


FIG. 13

cams *c*, *c*, on top of the reservoir. Some arrangement for equalizing the pressure on the top of the oil, as in the single-feed lubricator shown in Fig. 12, is also provided.

CYLINDER LUBRICATION

CYLINDER LUBRICATORS

22. When the oil is fed directly to the surface of the piston through the cylinder wall, it is evident that the piston must be a little longer than the stroke, so that some portion of the piston will always be over the opening through which the oil enters; otherwise, the front or back end of the piston will scrape the oil away, instead of working it between the piston and the cylinder wall. As the single-acting gas-engine piston serves also as a crosshead, it is always so long that this requirement is easily met. Oil is fed to the cylinders of horizontal stationary engines either from sight-feed oil cups or from some form of mechanical lubricator that delivers a fixed quantity of oil per revolution.

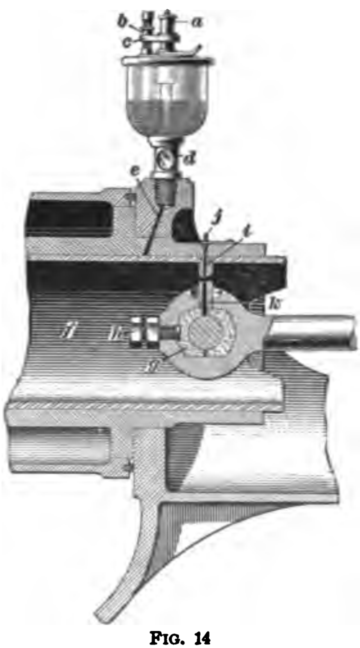


FIG. 14

23. Sight-Feed Lubricator.—When a sight-feed oiler is used, the cylinder, piston, and piston pin may all receive their lubricating oil from the same adjustable sight-feed oiler, as shown in Fig. 14. After the glass cup has been filled, the supply is regulated by the valve stem *a*, so that about five to ten drops of oil are fed per minute. Once adjusted, the valve is locked by the jam nut *b*. In order to turn on or shut off the oil feed, the arm *c* is turned to one side, which can be done without disturbing the

adjustment of the quantity of oil supplied to the piston. The sight glass *d* permits the operator to see whether the oiler is working properly. The oil passes through the hole *e* to the piston *f*, and is distributed over the surface by suitably cut oil grooves.

The piston pin is surrounded by the bronze bushing *g*, and the wear is taken up by the screw *h*. Oil is supplied from the oiler to the piston pin through the tube *i* when it registers with the hole *e*, or by hand when it registers with the hole *j* in the cylinder wall. The oil tube *k*, in the connecting-rod head, receives the oil from the tube *i* in the piston, being directly below it. In order to be sure that the piston pin is well oiled from the start, the crank-shaft is turned until the piston has reached its outer dead center, when the tube *i* will register with the oil hole *j* in the cylinder wall and the oil tube *k* in the connecting-rod head. Oil can then be supplied by a hand oiler direct to the piston pin. While the engine is running, some of the oil supplied to the piston finds its way through the tube *i*, whence it is conveyed either direct to the tube *k* or to the countersink in the connecting-rod head, which communicates with the hole in the tube *k* through small holes drilled horizontally into the wall of the tube on a level with the bottom of the countersink.

24. Pump Lubricator.—Ordinary cylinder oil tends to grow thick in cold weather, and to avoid this disturbing influence on the rate of feed, mechanical oilers are often used, which have, instead of the arrangement just described, one or more positive pressure pumps that deliver a definite quantity of oil for each revolution. In the most approved form, these lubricators have one small pump for each cylinder supplied, and often have other pumps to feed the main bearings. The stroke of the pump may be adjusted according to the sort of oil used. Some device of this sort is always necessary for engines working under extreme variations of speed, since any other method of feeding the oil would give too much or too little, according to whether the engine was running slow or fast.

25. Splash Lubricator.—In many vertical engines, the oil is not fed to the piston directly as described, but is splashed to it by the cranks. This arrangement has the advantage that the same splash of oil may be made to lubricate the valve mechanism and practically all other parts of the motor, including the crank-shaft bearings, over which pockets may be cast in the crank-case to catch the oil. When the splash system of lubrication is used, the oil may be delivered to the crank-case by an automatic pump, but it is more common to feed it periodically by hand. In stationary engines, a gauge is often attached to the outside of the crank-case, which shows the level of the oil within. In these engines, the crank-case is large enough to hold oil sufficient for several days' service.

Splash lubrication is used only on vertical engines, because in horizontal engines it would be impossible to prevent an excessive quantity of oil from being carried into the cylinder, where it would cause smoke in the exhaust and would speedily cover the igniter with soot and clog the valves.

CYLINDER OIL

26. There are three essential properties that a good gas-engine cylinder oil must possess.

1. It must have as high a fire-test as possible; that is, the temperature at which it gives off inflammable vapor should be as high as possible. In the best gas-engine cylinder oils, this temperature will be from 500° to 650° F., which is none too great considering the temperatures to which the oil is subjected when exposed to the burning charge in the cylinder.

2. As the oil is vaporized by the heat, it should leave as little residue as possible. Any cylinder oil will leave some carbon deposit, which gradually accumulates on the inner walls of the combustion chamber and on the piston head and valves, but it is desirable that this accumulation should be prevented as far as practicable. If it becomes thick, especially if the compression is high or if the form of the

combustion chamber is such that sharp corners are exposed to the heat of the flame, particles of the unburned carbon clinging to the walls or elsewhere may become heated to such a degree as to ignite the charge spontaneously before compression is complete.

3. The third requirement of a good gas-engine cylinder oil is that it shall have a fairly high viscosity; that is, it should be quite thick. The reason for this requirement is to be found in the high temperature of the cylinder, which is such that any ordinary oil will run on the piston much like water and lose practically all its lubricating qualities.

27. It is often advisable to use a higher grade of oil in an automobile engine than is necessary in a stationary engine, owing to the greater rapidity of the explosions in the former and the consequently higher internal temperature. As the cylinder head of an automobile engine is almost always cast in one piece with the cylinder, it is very hard to get at the combustion chamber to scrape the carbon deposit from it, and consequently it is well to use an oil that leaves as little deposit as possible. For air-cooled cylinders, only the heaviest oil obtainable and with the highest possible fire-test should be used, and the oil tank should be placed near enough to the cylinder or exhaust pipe to insure that the oil will not refuse to feed in cold weather.

28. Grade of Oil.—For ordinary water-cooled engines, except in the largest sizes, the grade of cylinder oil known as *heavy* is appropriate for summer use. In weather cold enough to cause this oil to stiffen, the next lighter grade, or *medium*, may be employed. In cold weather, if the medium oil does not feed freely, it is best to use a special oil suitable for use at low temperatures, though it is possible to thin the regular oil with kerosene or gasoline, to make it flow, and to increase correspondingly the feed of the oil cup or mechanical lubricator. It is best in every case to purchase oil that is known to be reliable. Besides, most manufacturers of automobiles purchase and sell oils marked with their own labels, which they recommend

for use in their engines. These oils may always be used with confidence in any engine of about the same character as that for which they are put up.

29. Should it be found impossible to obtain oil that is known to be suitable, the samples available may be tested for viscosity by putting a few drops of each on an inclined sheet of clean metal or glass, and noting the relative rapidity of their downward flow. The one that flows most rapidly has the least viscosity, and the one that flows most slowly has the greatest viscosity. The oils may be tested roughly for flashing point and for the carbon residue they leave by putting a little on a sheet of iron or tin plate, and heating gradually over a flame, taking care to move the plate over the flame so that all parts of it are evenly heated. The oils will become less viscous and will run on the plate, and for this reason two samples compared at the same time should not be placed too close together. They will gradually vaporize, leaving only a brownish and somewhat thick residue, which should be as small in amount as possible. A good, heavy oil will vaporize almost completely, but will retain considerable body even at temperatures where an oil of low fire-test would be entirely burned away. Oils, either heavy or light, that leave any considerable amount of black, tarry residue should be avoided.

30. Although, strictly speaking, cylinder oil needs to be used only for cylinder lubrication, it is the almost universal custom to use the same oil for all bearings of the motor. This simplifies the lubrication and removes the danger of making a mistake in oiling the pistons. Cylinder oil is an excellent lubricant for bearings subjected to hard service, as those of the crankpins and crank-shaft. The bearings do not require as much oil as the pistons, four or five drops a minute usually being amply sufficient.

BEARINGS

SHAFT BEARINGS

GENERAL CONSIDERATIONS

31. Definitions.—When it is the regular duty of a machine part to rotate, as when an axle or a shaft turns, it must be restrained or held at a definite place by a suitable support. A portion of the rotating part is in direct contact with the support that holds it and to which it fits. This contact portion of the rotating part is called the **journal,** and the part that surrounds and carries the journal is called the **bearing.**

When the bearing is made separate, it is called a **bushing,** or **sleeve,** if in one piece, and a **box,** if in two or more pieces. The term *bearing* is sometimes used, rather loosely, to mean both the journal and the bearing proper; the distinction made here, however, has the support of the best authorities.

32. Metals for Bearings.—Journals are commonly made of either iron or steel, while bearings are generally made of a softer metal. This is done for a two-fold purpose. In the first place, there is less friction between a journal of hard metal and a soft-metal bearing than between two hard metals. In the second place, it is cheaper to repair or replace a worn bearing than a worn journal. The principal metals used are brass or bronze and Babbitt metal. Brass is an alloy of copper and zinc; it varies in color from a bright yellow to a dark copper color. Some brasses are quite soft, while others are too hard for use as bearings. Bronze is an alloy of copper and tin, though lead is also added, at times.

Since brass and bronze are so extensively used for bearings, it has become a common practice to give the name of *brasses* to the two parts into which an ordinary brass or bronze bearing is usually divided.

Babbitt is also a soft metal, in fact much softer than brass or bronze; it is an alloy of tin, copper, and antimony, and sometimes lead or zinc. It is sold under a variety of special names, and the cheapest contains a large percentage of lead, while the better grades contain little or no lead.

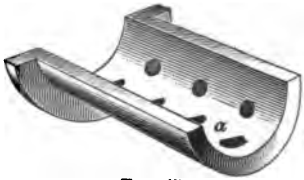


FIG. 15

The best bearings are probably those made of brass with Babbitt insertions at intervals over the bearing surface, as shown in Fig. 15. The brass may be drilled, as shown at *a*, or dovetail grooves may be planed in its surface, as shown at *a*, *a*, Fig. 16. The Babbitt is melted and poured in with the journal in place, or it may be hammered into place and bored to fit the journal. The great convenience of Babbitt as well as its anti-friction qualities make it the most common bearing metal. Cast-iron boxes are often lined with Babbitt and used with iron or steel journals. Sometimes, it is not wise to leave the journal in place while pouring the Babbitt, in which case a short piece of shafting of the same diameter as the journal may be adjusted and held in place by clamps while the metal is poured.

FIG. 16

33. Lubrication of Main Bearings.—It is impossible, even with the best lubricant, to eliminate friction entirely, but a proper use of oil or grease does much toward that end. The distribution of the lubricant over the bearing surface should be as uniform as possible, especially in the case of main bearings sustaining heavy pressures. This is often accomplished by grooves cut in the surface, sometimes in a **V** shape and sometimes in an **X** shape, as shown at *b*,

Fig. 16, the groove being semicircular in cross-section. The grooves extend nearly the length of the bearing, and the oil or grease that enters them flows toward the outer ends, lubricating the journal.

The lubricant is usually supplied to the bearing in a liquid form, and it flows easily through channels provided for it. Grease, on the other hand, is rather plastic, especially when cold, and needs to be forced into the bearing. This is done by the use of a cup having a spring-loaded piston, attached to the cover, that forces the grease down. When the bearing warms up, the grease becomes more fluid and flows readily to the rubbing surfaces.

TYPES OF BEARINGS

34. Classification of Main Bearings.—The oldest and simplest form of bearing used in gas-engine practice is the **plain bearing,** in which the journal of the shaft fits in a sleeve called the *bearing*, or *box*, and touches the supporting surface along its entire length. A type closely related to the plain bearing is the **ring-oiled bearing,** in which oil is carried to the journal by means of a ring. In **roller bearings,** rollers are interposed between the bearing and the journal, thus reducing the bearing surface and having rolling instead of sliding friction. In **ball bearings,** a number of balls surround the journal and lie between it and the bearing proper. Each ball thus touches the journal and the bearing surface in single points, instead of along lines. There is rolling friction, however, and the frictional resistance is much less than in ordinary bearings.

35. Plain Bearing.—The earliest bearings were of the plain type, and probably more bearings of this type are used at present than any other. A plain bearing is shown in Fig. 17 (*a*) and (*b*), the former being a section through the axis of the journal, and the latter an end view. The journal is shown at *a* and the brasses at *b* and *c*. The bearing is divided into two parts, the lower, which shows a part of

the frame or support *d*, and the upper part *e*, known as the *cap*. A plain bearing will give excellent results when well made and properly fitted. When worn, new brasses can

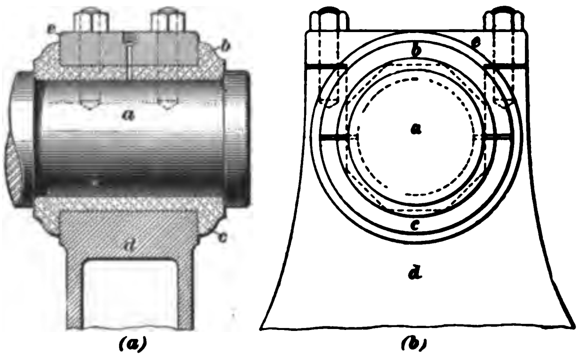


FIG. 17

be fitted and the bearing will be as good as when new. The brasses of a plain bearing may be provided with Babbitt inserts as shown in Figs. 15 and 16. Plain bearings are usually lubricated by allowing oil to flow between the rubbing surfaces by gravity from an oil cup.

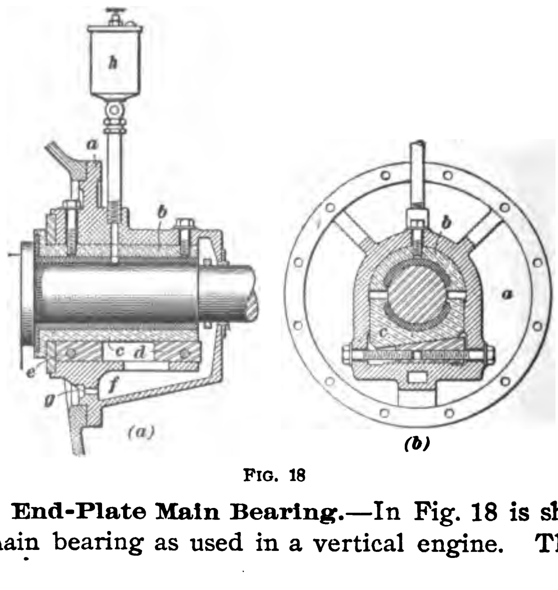


FIG. 18

36. End-Plate Main Bearing.—In Fig. 18 is shown a plain main bearing as used in a vertical engine. The box

is made in two parts, of brass or bronze, and is lined with Babbitt. The end plate *a* is circular and turned to fit the opening in the crank-case, to which it is bolted. The upper brass *b* is held in a central position on the shaft by two capscrews. There is little or no pressure on this brass, hence it does not wear; its duty is to prevent the shaft from lifting off the lower bearing and to aid in the distribution of the oil. The lower brass *c* is held in position by the weight of the shaft and the wedges *d* and *e*, which also serve to adjust the brass to the shaft so as to give as even a bearing between the shaft and the lower brass as possible. The screws on either side of each wedge are for the purpose of moving the wedges laterally for adjusting the brass and also to hold them in position when once properly adjusted. The chamber *f* below the bearing catches the surplus oil, and the hole *g* permits it to flow to the crank-case. Any surplus oil in the crank-case is drained off to a purifier or filter.

The adjustment of the lower brass permits the alinement of the shaft to be maintained. Any wearing away of the journal or bearing can be easily and quickly adjusted. The bearing is oiled by means of the sight-feed lubricator shown at *h*.

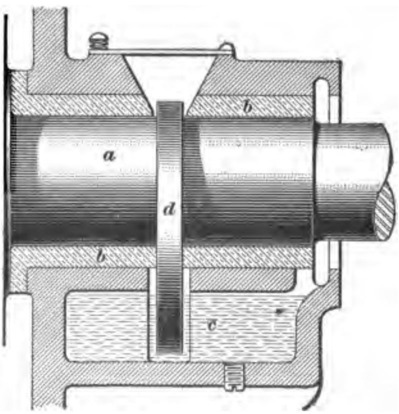
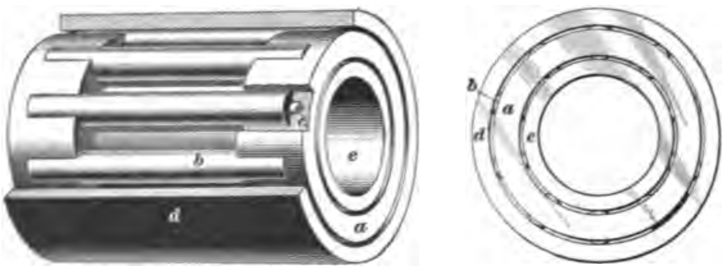


FIG. 19

37. Ring-Oiled Bearing.—A ring-oiled bearing is shown in Fig. 19, with the journal at *a* and the brass sleeve at *b*. An important part of this bearing is the oil reservoir *c* below the bearing and the ring *d* that rests on the journal and extends down into the oil. The ring is narrow and light, and when the engine is running, the upper part of the ring moves with the shaft; so that the lower part picks up the oil and raises it to the top of the shaft. By

this means, a good supply of oil is continually brought to the journal, keeping it well lubricated. Light chains are sometimes used for such work, instead of rings, and they have the advantage of being put in place easily on account of their flexibility.

38. Plain-Roller Bearing.—There are three types of rollers used in roller bearings, the plain cylindrical, the spiral, and the conical. The plain cylindrical roller bearing consists of a set of cylindrical rollers between the journal and a casing, or between a sleeve and a casing, as shown in Fig. 20. This bearing is made up of a strongly constructed cage *a*, with rollers *b* extending nearly the



(a) (b)

FIG. 20

whole length, a casing *d* outside the rollers, and a sleeve *e* inside. The cage simply holds the rollers, and does not come in contact with the sleeve *e*. The ends of the rollers are provided with balls *c*, which reduce the friction and wear, and keep the rollers in true alinement with the shaft. This prevents all twisting of the bearing, and makes it more reliable and satisfactory.

The roller bearing will not sustain as much of a load for the same size of journal as will the plain bearing. It will, however, reduce the friction for light or moderate loads when running at moderate speed. The plain rollers for bearings are usually made either hollow or solid, with the ends hollowed out for the supports that hold them in place. Solid rollers are cheaply made, and will sustain more weight than hollow rollers of the same size.

39. Plain-Roller Automobile Bearings.—An application of plain-roller bearings to the transmission gear of an automobile is shown in Fig. 21. The roller bearing

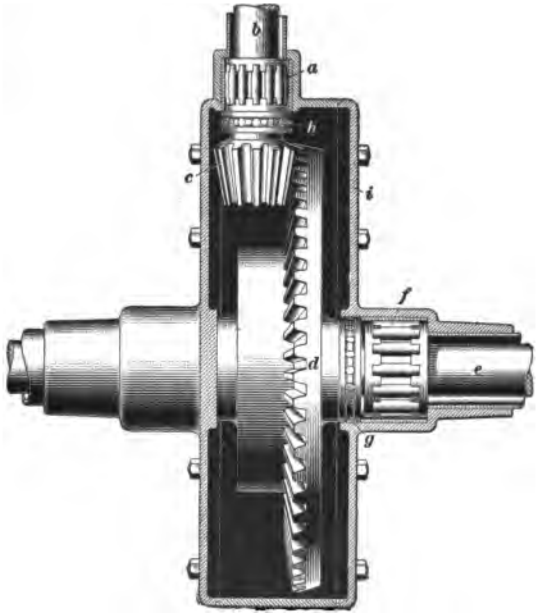


FIG. 21

shown at *a* is on the driving shaft *b* that transmits power through the bevel-gears *c* and *d* to the driving axle *e*. A second roller bearing is shown at *f* on the axle *e*, while at *g* and *h* are shown roller-thrust bearings for the purpose of taking the thrust of the shafts and preventing end motion. The gear-case *i* surrounds and protects the gears and bearings. The roller bearings *a* and *f* are the same as that shown in Fig. 20, the rollers being plain solid cylinders with ball-bearing ends. Thrust bearings will be described later.

40. Spiral-Roller Bearings.—In Fig. 22 is shown a roller bearing in which the rollers are made by winding square or rectangular bars into spirals in much the same way that a helical spring is made. The rollers are held in

FIG. 22

a cage formed of rings *a*, *a* held together by three pieces *b*, and have the projections *c* for retaining the rollers *d*.

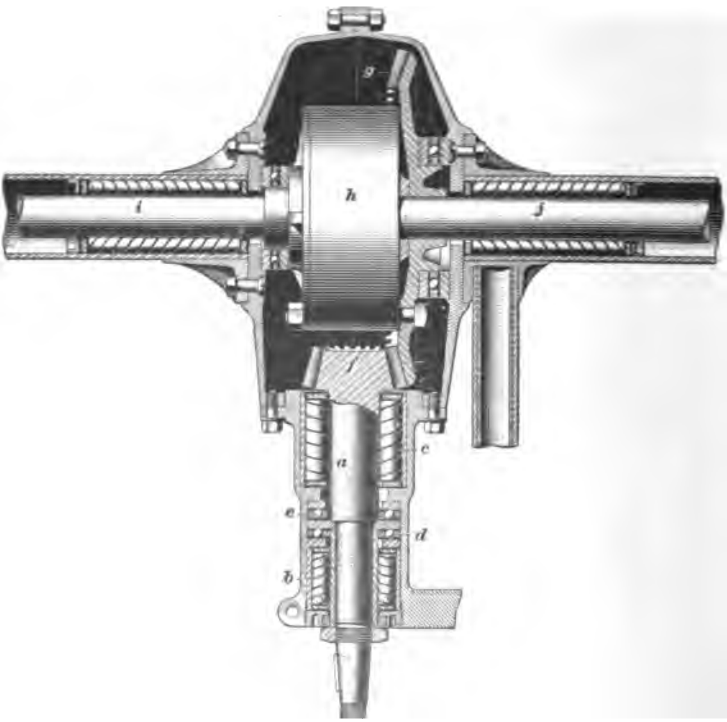


FIG. 23

The cage for holding the rollers is made of brass and fits them loosely, so as to allow free movement without increasing the friction. The hollow form of the rollers enables them to take in oil and distribute it, and permits the rollers to accommodate themselves to the surfaces upon which they roll. The inside casing is shown at *e* and the outside casing at *f*, the rollers being in contact with one or the other of these most of the time.

41. Spiral-Roller Automobile Bearings.—The application of spiral-roller bearings to automobile transmission gearing is shown in Fig. 23. The driving shaft *a* has two spiral-roller bearings *b* and *c* and two ball-thrust bearings *d* and *e*. The power is transmitted through the bevel-gears *f* and *g* to gears in the case *h*, which will be described later, and through which the power is transmitted to the driving axles *i* and *j*, they being entirely separate and independent. Each axle has its spiral-roller bearing and ball-thrust bearing. The spiral form of these rollers gives them flexibility, thus enabling them to fit any good bearing surface, and also distributes the lubricant to all parts of the bearing surface.

FIG. 24

42. Conical-Roller Bearings.—A somewhat different type of roller bearing is shown in Fig. 24. The rollers *a* are conical and grooved at the ends, and the grooves fit projecting rings on the inside cone *b* of the bearing. The outside ring or cup *c* is plain, and fits only the plain surface of the rollers. Both cup and cone are conical as well as the rollers. Adjustment for wear is provided by allowing the inner cone to be moved along the shaft, thus forcing the rollers against the outside cup. Such bearings are especially adapted for driving-axle bearings of automobiles.

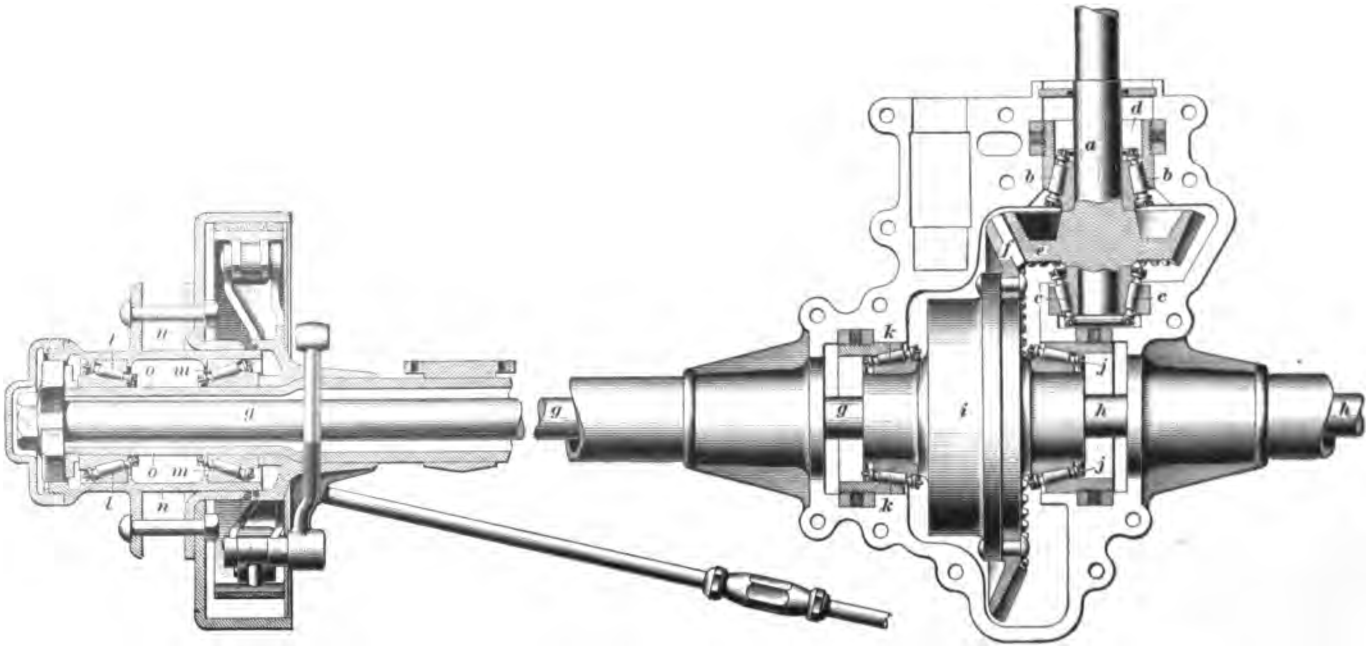


FIG. 25

as their tapered form takes care of the end thrust without the use of a special thrust bearing. The construction of the cage for holding these rollers in position and preventing them from getting too far out of line resembles the construction for the cylindrical-roller bearings shown, except that in this case the rollers are held in place by projections that fit in holes in the cage. The form of the rollers and inside cone is intended to give true rolling contact without sliding.

43. Conical-Roller Automobile Bearings.—Several conical-roller bearings as applied to the main driving mechanism of an automobile are shown in Fig. 25. The driving shaft *a* is supplied with two conical-roller bearings, shown at *b* and *c*. They taper in opposite directions, thus holding the shaft firmly in position against any force that might produce end motion. The cup *d* is threaded on the outside to permit of adjusting the bearing for wear. The bevel-gears *e* and *f* transmit the power to the driving axles *g* and *h* through the differential gears in the case *i*. The conical-roller bearings *j* and *k* keep the axles in position, and are provided with adjusting cups, as in the bearing at *a*. At *l* and *m* are shown similar conical-roller bearings between the wheel hub *n* and the axle sleeve *o*. The inclination of these bearings is such as to keep the hub in position without providing a special thrust bearing.

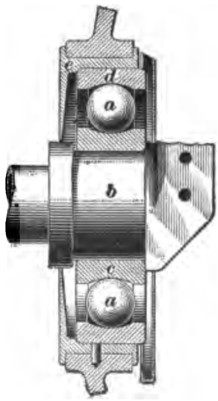


FIG. 26

44. Ball Bearings.—A ball bearing consists of one or more circles of balls with inside and outside casing in which the balls run. They are rarely used on stationary gas engines, but are used to some extent on automobile engines. Fig. 26 shows a ball bearing as applied to the crank-shaft of an automobile engine. Two of the balls are shown at *a*, *a*, the journal at *b*, and the ball races or casings at *c* and *d*. The ring *e* surrounds the ball bearing and holds it in place, the casings *c* and *d* being made in halves, or split. The casing *c*

turns with the journal *b*, while the casing *d* remains stationary; so that, as the shaft turns, the casing *c* rolls on the balls *a*. The bearing surface of a ball bearing is very small, and the pressure per square inch of bearing surface is correspondingly large; consequently, single circles of balls cannot be used on bearings that sustain any considerable pressure. They should be lubricated, but if protected so as to be free from dust or dirt they require very little lubrication.

OIL GROOVES IN BEARINGS

45. Oil should always be fed to a bearing on the unloaded side, and the oil grooves in a bearing should be on the same side. It is a somewhat common but poor practice to cut oil grooves in the loaded side of a bearing. The effect of this is that the oil is squeezed out from the bearing under the load. If the oil is supplied in abundance to the unloaded side of the bearing, it will be carried around by the turning of the shaft. In oiling systems in which the oil is fed rapidly to a bearing, and is collected and used over again after it works out, the best plan is not to extend the oil grooves the length of the bearing, as is often done, but to limit the grooves to about one-half of the length of the bearing, locating them as near the middle as possible. This will cause the oil to flush the bearing continually as it works out at the ends, thereby carrying with it the metal worn from the bearing surfaces.

46. It is particularly common to find the crankpin brasses grooved on the pressure side as well as on the cap side, the reason generally being that, when the splash system is used, the oil is introduced on this side. If trouble is experienced with crankpin bearings arranged in this manner, in a vertical motor with splash lubrication in the crank-chamber, it will be well to fill up the grooves in the pressure brass with solder, and supply the oil wholly through the bottom brass. To do this, a hole should be drilled and tapped in the cap for a piece of brass tubing $\frac{5}{16}$ inch outside diameter, as shown in

Fig. 27. The tube *a* should be bent so that, when it dips into the oil on the bottom swing of the crank, it will act as a scoop, and the lower end of it is preferably beveled off as the sketch indicates, so as to give an elongated opening. The tube is firmly fastened in the cap *b*, and the brass *c* has an oil hole *d* about $\frac{5}{16}$ inch in diameter drilled through it, connecting with a deep, cross-shaped groove *e* from $1\frac{1}{4}$ to 2 inches long. On the bottom swing, the oil will be scooped up into the groove *e*, which will retain enough of it during the remainder of the revolution to lubricate the bearing. Another arrangement is to cut a hole about $1\frac{1}{4}$ inches square through the cap brass, and fill it with a felt pad a little thicker than the brass itself, so that it will be under slight compression. This pad will absorb the oil and transmit it to the bearing. Unless provision is made by one of these methods for retaining the oil as it comes up, it is likely to be thrown out by centrifugal force.

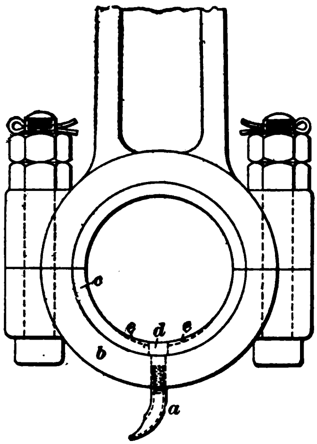


FIG. 27

TAKING UP WEAR IN BEARINGS

47. Some forms of connecting-rods are provided with easy means of taking up wear on the bearings in the shape of shims, or thin strips of copper or brass, which are interposed between the large end of the connecting-rod and the bearing cap. The cap is bolted down tight against these shims, and when the bearing becomes worn one or more shims are taken out on each side. Provided that the bearing has not been cut and is not badly worn out of shape, this will take up the wear satisfactorily. Care should be taken in doing it that there will be not the slightest evidence of tightness or binding after the bolts have been tightened. If the

bearing is in the slightest degree tight, it will squeeze the oil out and begin to overheat and cut.

If the crankpin bearing is not provided with shims, it becomes necessary to file the flat face of the cap where it abuts against the large end of the rod, in order to close up the bearing. This must be done with great care, in order to avoid taking off more metal at one end of the bearing than at the other, which would cause it to be tight at that end. The work should be done slowly, the cap replaced frequently, and the tightness of the bearing tried.

If the bearing is already cut, or if it is worn badly out of shape, so that the connecting-rod will rock sidewise when the brasses are brought together as close as they will come without binding, it is necessary to scrape the bearing to a fit.

48. The scraping of a bearing, whether a crankpin bearing or a main bearing, is done with tools called **scrapers,** two of which are shown in Fig. 28. Old three-cornered or half-round files, with the teeth ground off and the edges worked down smooth on an oilstone, make

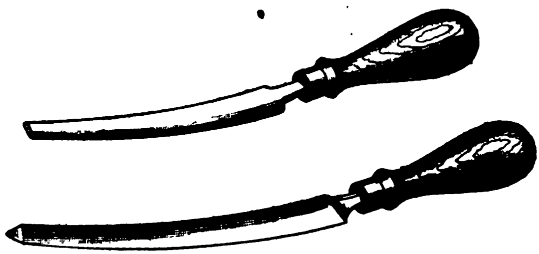


FIG. 28

very good scrapers. When a bearing has been scraped approximately true, the crankpin should be rubbed lightly with red lead or graphite mixed with oil, and the bearing replaced. The shaft should then be revolved a couple of times, and when the bearing is taken apart again the high spots on the brasses will be indicated by the red lead on them. These should be scraped down, the brasses again fitted on the pin, and the operation repeated until the brasses bear evenly on the journal.

It is very essential that the bearing shall be scraped true, so that the connecting-rod will be perfectly square with the shaft. Unless this is done, the pressure will come at one end of the bearing, which is likely to be speedily ruined. For this reason, the novice should not undertake the work, but should employ an experienced machinist, or send the engine to a repair shop.

49. Frequently, the meeting edges of the crankpin brasses are beveled, as shown at *a*, *a*, Fig. 29. This is done to prevent possible binding of these edges, which receive little, if any, of the pressure on the piston. It is better, however, not to extend the bevel out to the ends of the bearing, as that permits the oil accumulating in the grooves formed by the bevels to escape instead of being carried around the pin.

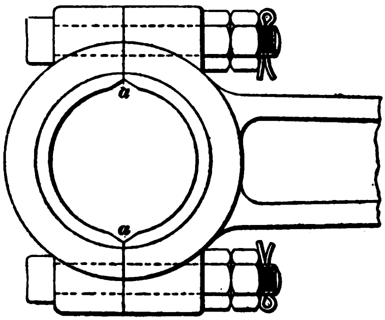


FIG. 29

It will sometimes be found that the crankpin itself has been worn out of round, being flattened on one side. When this is the case, it is useless to take up the lost motion in the bearing before the crankpin itself has been trued up by turning it in a lathe or grinding it.

GRAPHITE FOR BEARINGS BEGINNING TO CUT

50. If a bearing has begun to cut, further cutting may be prevented by taking out the shaft and polishing the journal with the finest emery cloth and oil, and wiping it clean before returning it to position in the bearing. On reassembling, a little of the finest flake graphite is stirred into some cylinder oil, and the bearing oiled freely with the mixture. Unless the oil is so thin that the graphite settles, the latter will aid greatly in protecting the bearing from

further cutting. A very small quantity of graphite may be mixed with the oil in the reservoir, but its use should soon be discontinued if the same reservoir feeds the cylinders, as the graphite may get on the spark plugs, and if it is allowed to settle in a check-valve or sight feed it will clog it.

MISCELLANEOUS BEARINGS

STERN BEARINGS, STUFFINGBOXES, AND STRUTS

51. Stern Bearings.—In marine practice, the stern bearing of the propeller shaft is usually fastened to the stern post of the boat. Stern bearings are ordinarily made of bronze and are of various shapes and designs. A type of plain bronze stern bearing is shown in Fig. 30. These bearings may be lined with Babbitt, or with a bar of tough wood known as *lignum vitæ*.

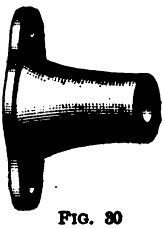


FIG. 30

52. Stuffingboxes.—Stuffingboxes inside the stern bearing are used to prevent water from leaking into the hulls of boats around the propeller shafts. In smaller boats, they may be used in place of stern bearings, and are frequently placed on the outside. Such a stuffingbox is shown in Fig. 31, with the bearing part at *a*, the cap or gland at *b*, a lock-nut at *c*, and the propeller shaft at *d*. In this form of stuffingbox the thread is frequently made so that the rotation of the shaft when the boat is traveling forwards will tend to tighten the gland. Many manufacturers, however, use right-hand screw threads, regardless of the direction of rotation.

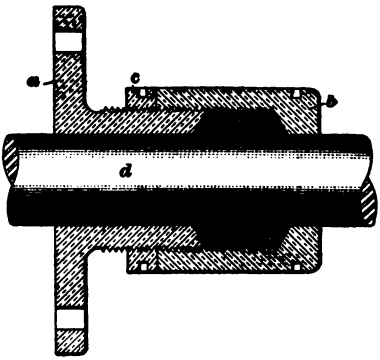


FIG. 31

Stuffingboxes are sometimes placed inside of boats instead of outside. Such stuffingboxes have the advantage that they can be tightened, if necessary, without hauling the boats out of the water. The packing used in stuffingboxes must be some soft material little affected by water; braided flax is ordinarily used.

53. Struts.—Where the end of a propeller shaft extends to quite a distance beyond the hull of the boat an outer bearing is necessary, and this is termed a **strut.** It is usually made of bronze with a Babbitt lining, and is fastened to the hull by means of two rather wide flanges. After the bearing is fastened it is babbitted with the shaft in place, with a thin piece of paper around the shaft to permit some clearance, thus making allowance for possible swelling or shrinking of the wood.

SPRING BEARINGS

54. When there is a considerable distance between the principal bearings of a long shaft, the shaft may sag somewhat, causing heating of the bearings and unpleasant vibration. To obviate these results, **spring bearings** are often used, especially in the case of long propeller shafts. Fig. 32 shows a form of spring bearing made of cast iron, though other metals may be used. It consists of a bushing *a* held in place by the cap *b*, and is supported by arms *c*, which are thin enough to make flexible and give spring to the bearing. The bearing is lubricated by means of the grease cup *d*. Sometimes, these bearings are lined with Babbitt or *lignum vitæ*.

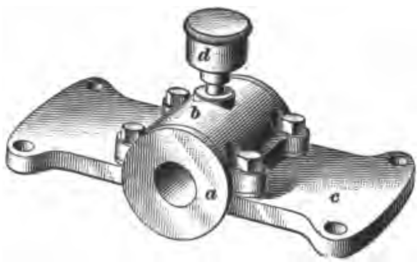


FIG. 32

THRUST BEARINGS

55. **In the case of a propeller shaft in a motor boat**—that is, in a boat propelled by a motor or engine—it is necessary to provide some kind of a bearing to take the thrust of the propeller and prevent end movement of the shaft. Such a bearing is known as a **thrust bearing,** one form of which is shown in Fig. 33. The journal *a* is provided with collars *b*, *b*, that fit into grooves *c*, *c* in the bearing. The bearing is sometimes made with only one collar on the journal, but in that case it is necessary to have a large collar. In order that the bearing shall run without heating, it is necessary to have sufficient bearing surface so that the pressure per square inch shall not be excessive. This is accomplished better with several collars than with one, or only a few, besides making the journal and bearing less cumbersome.

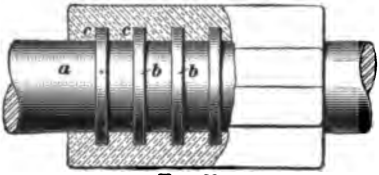


FIG. 33

56. Roller and Ball-Thrust Bearings.—A plain roller-thrust bearing is shown in Fig. 34. The thrust

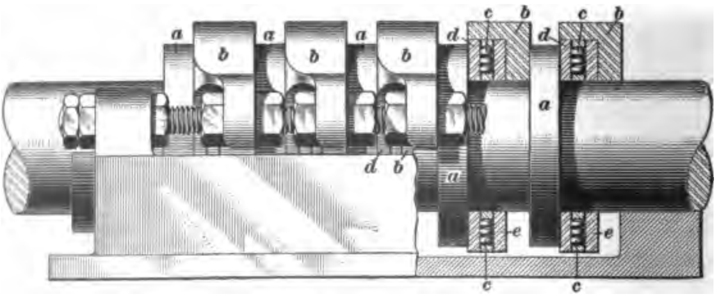


FIG. 34

collars *a*, *a* form part of the shaft, while the pieces *b*, *b* are part of the bearing. The rollers are shown at *c*, *c*, and the rings on each side of the rollers are shown at *d*, *d* and *e*, *e*. The part *b*

is a yoke against which the pressure is exerted and which is held rigidly to the frame of the bearing. The hardened ring *e* is placed between the yoke and the rollers, while the ring *d* lies between the rollers and the collar on the journal

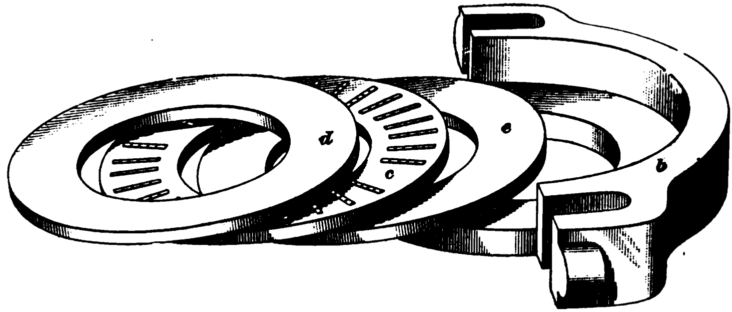


FIG. 35

A better idea of the parts of the bearing may be obtained from Fig. 35, which, however, shows a slightly different form of lug on the yoke. The parts are lettered as in Fig. 34.

FIG. 36

This general form of bearing is also made without rollers, and in that case the collars *a* bear directly against the yokes *b*.

Instead of using cylindrical rollers, as shown in Fig. 34, the rollers are sometimes made conical, as shown in Fig 36. The rollers *a* are held in the cage *b* by pins with ball-bearing ends. The hardened rings *c* and *d* are also conical, and are ground accurately to the proper form.

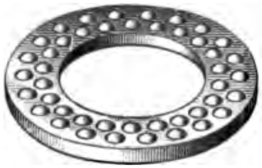


FIG. 37

Ball-thrust bearings are sometimes used, the balls being held in a cage as shown in Fig. 37. Hardened rings are, in this case, used on either side of the ball cage, as in roller bearings.

HOT BEARINGS

CAUSES AND PREVENTION OF HOT BEARINGS

57. Causes.—Hot bearings are a source of much anxiety and annoyance to the engineer, and interfere very seriously with the proper working of the engine.

The various causes of hot bearings may be stated as follows:

Newly-fitted brasses and journals
Refitted brasses and journals
Brasses set up too tightly
Brasses too loose
Warped and cracked brasses
Cut brasses and journals
Imperfectly fitted brasses
Brasses pinching the journal at their edges
Oil feed stopped entirely
Not enough oil
Dirty and gritty oils, or oils of poor quality
Oil squeezed out of the bearings
Grit from any source in the bearings
Premature ignition
Journals too small, either in diameter or in length
Overloaded engine

Engine out of line
External heat
Brasses fitted too snugly between collars of journal
Springing of bedplate
Springing or shifting of pedestal or pillow-block

58. Adjustment of Bearings.—Some engineers consider it an error to make bearings adjustable; they say it gives an opportunity for careless men to do damage through lack of judgment. It is true that one of the principal causes of hot bearings is setting up the brasses too tightly. Some persons, as soon as they hear a pound or noise about an engine, immediately conclude that some bearing is slack and tighten it up. There are numerous other causes of pounding in engines besides slack bearings, and the engineer should be fully convinced that the pound is caused by slack brasses before setting them up. Bearings on an engine that is in line and in good order, if properly adjusted, will run smoothly and noiselessly for months without further adjustment, and it should be the object of an engineer to get his engine into that condition as soon as possible and to keep it so.

59. Observation of Bearings.—Bearings, particularly those of large engines, require constant watching. The engineer or oiler should know at all times the condition of every bearing and oil cup; this will make it necessary that the oil cups be examined frequently, to ascertain if they are feeding and if they contain sufficient oil, and that the oil in the cups be replenished whenever necessary. While making his rounds the engineer should feel with the palm of his hand the brasses of those bearings that have shown a tendency to heat and those that are most liable to heat.

GENERAL TREATMENT OF HOT BEARINGS

60. Mixtures for Reducing Friction.—Should any of the bearings show an inclination to heat, as indicated by their temperatures rising above the temperature of the surrounding

atmosphere, the oil feed should be increased; if the oil does not feed freely, run a wire through the oil tubes. If the bearing continues to get hotter, mix some flake graphite, flour sulphur, or powdered soapstone with the oil, and feed the mixture into the bearing through the oil holes, between the brasses, or wherever else it can be forced in. A little aqua ammonia introduced into a hot bearing will sometimes check heating by converting the oil into soap, which is an excellent lubricant. Mineral oils will not saponify.

61. Danger of Increased Heating.—If, after trying the remedies just mentioned, the bearing continues to grow hotter, say to the extent of scorching the hand or burning the oil, it indicates that the brasses have been expanded by the heat and that they are gripping the journal harder and harder the hotter they get; at this stage, if the engine is not stopped or if the heating is not checked, the condition of the bearing will continue to grow worse as long as the engine is running, and may become so bad as to slow down and eventually stop the engine because of excessive friction. By this time the brasses and journal are cut and in bad condition generally, and the engine must be laid up for repairs.

62. Remedies for Increased Heating.—The condition mentioned in Art. **61** should not be permitted. After the simple remedies given in Art. **60** have been tried and have failed to produce the desired result, the engine should be stopped and the cap nuts or key of the hot bearing should be slacked back and the engine allowed to stand until the bearing has cooled off. If necessary, the cooling may be hastened by pouring cold water upon the bearing, though this is objectionable, as it may cause the brasses to warp or crack by unequal contraction. Putting water on a very hot bearing should be resorted to only in an emergency, that is, when an engine *must* be kept running regardless of a spoiled pair of brasses. Water may be used on a moderately hot bearing without doing very much harm.

If the engine is not started again until the faulty bearing

has become perfectly cool, the cap nuts or key should be set up a little before starting; otherwise, the brasses that have been slacked off may be too loose, and excessive thumping and pounding will result.

63. Dangerous Heating.—Should a bearing become so hot as to scorch the hand or burn the oil, it is imperative that the engine should be stopped, at least long enough to loosen up the brasses, even though it is necessary to start up again immediately; otherwise the brasses will be damaged beyond repair and deep grooves cut into the journals. If the brasses are babbitted, the soft metal will melt out of the bearing at this stage, disabling the engine. If there is not an extra set of brasses on hand, the engine cannot be used until the old brasses are rebabbitted, or until a new set is made and fitted.

64. Keeping Engine With Hot Bearing Running. If it is absolutely necessary in an emergency to keep the engine running while a bearing is very hot, the engineer must exercise his best judgment as to how he shall proceed. After slacking off the brasses, about the best he can do is to flood the inside of the bearing with a mixture of oil and graphite, sulphur, soapstone, etc., and the outside with cold water from buckets, sprinklers, or hose, taking the chances of ruining the brasses and cutting the journal. Of course, the engine must be stopped as soon as the emergency has passed, and the journal then stripped. It is to be expected that the journal will be found to be deeply grooved and the brasses cut and warped. If the brasses are babbitted, most of the Babbitt metal will have melted out. But if the brasses are made solid, they can be refitted for at least temporary use or until new ones can be procured.

65. Refitting a Cut Bearing.—The wearing surfaces of the brasses and journal must be smoothed off as well as circumstances will permit; but if the grooves are very deeply cut, it will be useless to attempt to work them out entirely, and if the brasses are very much warped or badly

cracked, it will be best to put in new ones if any are on hand. If not, the old ones must be refitted and used until a new set can be procured, which should be done as soon as possible. As for the journal, temporary repairs can be made by smoothing it, but at the first opportunity the journal should be turned in a lathe and the brasses properly refitted or replaced with new ones.

After a bearing has once been heated sufficiently to cut the brasses and journal or to warp or crack the brasses, it is afterwards constantly in danger of heating again, and the engine is thereby rendered unreliable.

CAUSES AND CURE OF HOT BEARINGS

66. Newly-Fitted Brasses and Journals.—The bearings of new engines are particularly liable to heat, due to the wearing surfaces of the brasses and journals not having reached a perfect fit; therefore, if a new engine or one with new brasses is run at moderate speed and under light load, with rather loose brasses, until the journals and bearings adapt themselves to each other, there will be little danger of the bearings heating thereafter, if proper attention is given to their adjustment and lubrication.

67. Uneven Bearing of Brasses.—In order that a bearing may run freely, there must be a little play between the brasses and their beds; this permits a slight movement of the brasses when pressure is exerted on them by the shaft; and notwithstanding the fact that they may have been most carefully fitted in the shop, they must be run a certain amount in order to properly adjust themselves. This is especially the case with the bearings of large engines, and the same conditions will obtain every time the brasses are removed. It seems almost impossible in practice to put the brasses of a large bearing back again just where they were before removal; it always requires time for them to settle into their old places; therefore, they should not be disturbed unless there is a positive necessity for doing so.

The direct cause of the tendency to heat in this instance is that the brasses do not bear evenly on the journal after the several parts of the bearing are assembled.

68. Refitted Brasses and Journals.—The bearings of an engine that has just been thoroughly overhauled and the journals and brasses of which have been refitted are liable to heat. The wearing surfaces of the brasses having been newly worked or machined, the surface of the metal is not smooth, and the brasses have not yet had a chance to adjust themselves to the journal. The engine, therefore, is in about the same condition as a new engine, so far as the bearings are concerned, and should be treated in the same manner; that is, it should be run moderately until the brasses have accommodated themselves to the journal.

69. Brasses Set Up Too Tightly.—When the brasses of an engine bearing are set up too tightly, heating is inevitable, and probably more hot bearings result from this cause than from any other, and with less excuse. It is often the case that an attempt is made to stop a knocking or pounding in an engine by setting up the brasses when the pounding could and should be stopped in some other way.

The direct cause of heating of bearings when the brasses are set up too tightly is the abnormal friction that is produced by the pressure of the brasses on the journal. The prevention and cure are obvious. The brasses should not be set up too tightly, and if they are, they should be slacked off as soon as possible. Hot bearings should never occur from this cause. Only a competent person should have charge of the bearings, and no one else should be permitted to adjust them.

70. Brasses Too Loose.—Bearings may heat on account of the brasses being too loose. The heating is caused by the hammering of the journal against the brasses when the crankpin is passing the dead centers. This fault is easily remedied, however, by setting up the cap nuts or key. Here the experience and judgment of the engineer are

called into play to decide just how much to set up, as it is very easy to overdo the matter and set up too far, with a hot bearing as the result.

Most engineers have their own particular views regarding the setting up of bearings. One method is to set up the cap nuts tight and then slack them back a half turn; if the brasses are still too loose, they are set up again and slacked back less than before, repeating the operation until the ideal position is reached—that is, when there is neither pounding nor heating. It is important that this desired point be approached very gradually and carefully, else the chances are that it will be overreached and the operation will have to be repeated.

71. Another method of setting up journal brasses is as follows: Fill up the spaces between the brasses with thin metal liners, say from 18 to 22 Birmingham wire gauge in thickness, and a few paper liners for fine adjustment; put in enough of them to cause the brasses to set rather loosely on the journal when the cap nuts or keys are set up solid. Run the engine for a while in that condition and note the effect; then take out a pair of the liners and set up solid again. Repeat this operation until there is neither thumping nor heating. If this system of treating bearings is carefully carried out, there will be very little danger of their heating. When the proper adjustment is reached, the engine should run a long time without requiring any further adjustment of the bearings. In removing the liners, great care should be exercised not to disturb the brasses any more than is absolutely necessary. A pair of thin, flat-nosed pliers will be found useful in slipping out the liners. This method is preferable to the first one mentioned, because there is not so much danger of setting the brasses up too far.

72. Warped and Cracked Brasses.—Warped and cracked brasses will cause heating, because they do not bear evenly on the journal, and hence the pressure is not distributed over the entire surface, as it should be. The remedy will depend on the extent of the distortion of the brasses

If the distortion is not too great, the brasses may be refitted to the journal by filing and scraping; but if they are twisted so much that they cannot be refitted, new brasses must be put in.

73. Cut Brasses and Journals.—Brasses and journals that have been hot enough to be cut and grooved are liable to heat again at any time, on account of the undue friction produced by the roughness of the wearing surfaces. As long as the grooves in the journal match the grooves in the brasses, the friction is not greatly increased; but if a smooth journal is placed between a set of brasses that are cut and pressure is applied, the journal crushes the ridges on the brasses, the friction becomes very great, and heating results.

The way to prevent heating from this cause is to work the grooves out of the journal and brasses by filing and scraping as soon as possible after they occur.

74. Imperfectly Fitted Brasses.—Faulty workmanship is a common cause of the heating of a bearing. The brasses in that case do not bear fairly or set squarely in their beds, and while they appear right to the eye, they may not be square in the bearing. A crankpin brass must set squarely on the end of the connecting-rod and the rod itself must be square. If the key, when driven, forces the brasses to one side or the other and twists the strap on the rod, the brasses will not set squarely on the pin and will bear harder on one side than on the other. The same is true of the shaft bearings. If the brasses do not bed fairly on the bottom of the casting or do not go down evenly, without springing in any way, they will not run as they should, and heating will result. Continual heating of bearings is almost always caused by badly fitting brasses. This is a defect that should be looked for and, if found to exist, should be remedied at once.

In many cases, trouble with connecting-rod bearings can be traced to crankpins that are not perfectly round. With crankpins from .003 inch to .005 inch out of round, it would become absolutely impossible to keep the bearings in good working order.

75. Brasses Pinching the Journal at Their Edges. When first heated by abnormal friction, brasses tend to expand along the surface in contact with the journal; this will tend to open the brass and make the bore of larger diameter if it is not prevented by the cooler part near the outside and by the bedplate itself.

If the brass becomes hot very quickly, the resistance to expansion produces a permanent set of the metal near the journal, so that, on cooling, the brass closes and grips the journal; it will then set up sufficient friction to heat again and expand sufficiently to ease itself from the journal, and so long as that temperature is maintained the journal runs easily in the bearing. This is why some bearings always run somewhat warm and will not work cool. A continuance of heating and cooling will set up a mechanical action at the middle of the brass, which must eventually end in cracking it, just as a piece of sheet metal is broken by continually bending it backwards and forwards about a certain line.

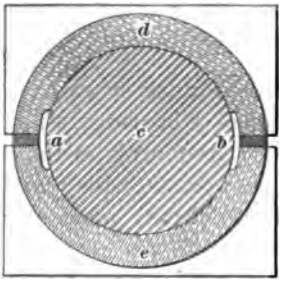


FIG. 38

The heating by the brasses pinching the journal may be prevented by chipping off the brasses at their edges parallel to the journal, as shown at *a* and *b*, Fig. 38, in which *c* is a sectional view of the journal and *d* and *e* represent the top and bottom brasses.

76. Oil Feed Stopped.—It does not take long for a bearing to get very hot if it is deprived of oil. The two principal causes of a bearing becoming dry are an oil cup that has stopped feeding, either because it is empty or because it is clogged by dirt in the oil, and oil holes and oil grooves closed by dirt or by the gumming of the oil. Both of these conditions are the direct result of negligence, and their existence can always be prevented by the exercise of reasonable care.

77. Not Enough Oil.—The effect produced on a bearing by an insufficient oil supply is similar to that of no oil, only in a lesser degree. Of course it will take longer for a bearing to heat with insufficient oil than with none at all, and the engineer has more time in which to discover and remedy the difficulty. As a rule, however, more oil is used on bearings than is actually necessary, and a waste of oil is the result. A steady feed, a drop at a time, gives the best results.

78. Dirty and Gritty Oils, and Oils of Poor Quality. Oils containing dirt and grit or that are deficient in lubricating quality cause hot bearings; but it is within the power of the engineer to guard against such causes. There is a great deal of dirt in lubricating oils of the average quality; therefore, all oil should be strained through a cloth or filtered, no matter how clear it looks. All oil cups, oil cans, and oil tubes and channels should frequently be thoroughly cleaned. Oil may be removed from the cups by means of an oil syringe. All oil removed from the cups and cans should be strained or filtered before it is used. If these instructions are strictly followed, most of the danger of bearings heating from the use of dirty or gritty oils will be avoided.

There is such a great variety of lubricating oils on the market whose quality cannot be definitely decided on without an actual trial that it is a difficult matter to avoid getting poor oil sometimes. About the only way to meet this trouble is to pay a fair price to a reliable dealer for oil that is known to be of good quality. Cheap oils are generally very deficient in lubricating qualities, and hence should be avoided, as should also gummy oils, which choke the oil channels and cause the brasses and journals to stick together when the engine is stopped over night.

79. Oil Squeezed out of Bearings.—Bearings carrying very heavy shafts sometimes refuse to take the oil, or, if they do, it is squeezed out at the ends of the brasses or through the oil holes, when the journals will run dry and heat. The great weight of the shaft causes the journal to

hug the bottom brass so closely that the oil cannot penetrate between them, or, if it does, it is immediately forced out. Large journals require oil of a high degree of viscosity, or *heavy oil*, as it is generally called. Oil of this character does not work its way under a heavy shaft as easily as a thin oil, but thin oil has not the body necessary to lubricate a large journal.

This difficulty may be met by chipping oil grooves or channels in the brasses. A round-nosed cape chisel, slightly curved, is generally used for this purpose, taking care to smooth off the burrs made by the chisel; a steel scraper or the point of a flat file will do this. The grooves are usually cut into the brass in the form of a **V** if the engine is required to run only in one direction; if it is to run in both directions, the grooves should form an **X**. In the first instance, the grooves should spread out from their junction in the same direction as that in which the journal turns. The oil grooves may be from $\frac{1}{8}$ to $\frac{1}{4}$ inch wide and about $\frac{1}{8}$ inch deep.

80. Grit in Bearings.—Grit is an ever-present cause of heating of bearings; it is only by persistent effort on the part of the engineer that he can keep his machinery running cool in a dusty atmosphere. The causes of this condition are innumerable; it is, therefore, only possible to mention a few of them here. Work done on a floor over an engine shakes dirt down upon it at some time or other; all floors over engines should therefore be made absolutely dust-proof by laying paper between the flooring. A prolific cause of hot bearings from grit in producer-gas engines, especially when the engine and producer rooms communicate, is carelessness in handling the ashes and clinkers. If piles of red-hot clinkers and ashes are deluged with buckets of water, the water is instantly converted into a large volume of steam that rises suddenly, carrying with it large quantities of small particles of ashes and grit that penetrate wherever it has access, and will find its way into the engine bearings. Throwing large quantities of water on the hot clinkers and ashes should be avoided; sprinkle them instead,

and close the producer-room door while the ashes and clinkers are being hauled or wet down or while the fire is being cleaned or hauled.

81. If emery, emery cloth, Bath brick, or other gritty cleaning material is used about a bearing, it is sure to get inside and cause trouble; it is, therefore, better not to use them close to a bearing.

As a precaution against grit getting into a bearing, all open oil holes should be closed with wooden plugs or clean cotton waste as soon as possible after the engine is stopped, and should be kept closed until ready to oil the engine again preparatory to starting up. Plaited hemp or other suitable covering should also be laid over the spaces between the ends of the brasses and the collars of the journals of every bearing on the engine, and kept there while the engine is standing still.

Bearings are now in use that, it is claimed by their makers, are dust-proof, but their use does not relieve the engineer from the responsibility of taking every precaution possible to keep grit and dirt out of the bearings of his engine.

82. Premature Ignition.—Bearings designed to stand a given amount of pressure will begin to heat if this pressure is greatly and constantly exceeded. Premature ignition of the incoming charge caused by various conditions will result in abnormally high initial pressure and severe shocks upon the bearings. Experience shows that the crankpin especially will heat under such conditions. The remedy consists in finding the actual cause of the premature firing and using the proper means to stop it.

83. Journals That Are Too Small.—Journals that have insufficient area of wearing surface will heat. In practice, only a certain amount of pressure per square inch of area can be sustained by a bearing before the friction reaches the point that will cause heating.

The pressure that a bearing will sustain per square inch

of area of rubbing surface without heating depends on the materials of which the journal and brasses are composed, the fineness of their finish, the accuracy of their fit, the adjustment of the brasses, and the lubricant used.

Pressure and friction have a direct relation to each other. The total amount of friction of two bodies in contact depends on the pressure of the one on the other and is nearly independent of the area of the surfaces in contact. The total pressure on the bearing divided by the projected area, that is, the product of the length and the diameter of the bearing, in inches, gives the bearing pressure per square inch. If the allowable bearing pressure per square inch is exceeded. heating is liable to occur, for the heating is proportional to the friction produced, and the friction per square inch depends on the bearing pressure per square inch. Hence, less friction is produced per square inch of surface by a long journal than by a short one of equal diameter with the same total pressure; therefore, a long journal is not nearly so liable to heat as a short one of the same diameter, and a journal of large diameter is not so liable to heat as one of small diameter of equal length. It is the aim of the designer to so proportion the journal that the pressure per square inch of bearing surface shall not exceed the safe limit for the given conditions.

There is only one cure for a bearing that heats constantly because it is too small, and that is to make it larger if circumstances permit this to be done. If this is impossible the best of lubrication must be used, and, if necessary, water must be run constantly on the bearing.

84. Overloaded Engines.—The effect produced by overloading an engine is similar to that when the journal is too small. The pressure on the brasses being increased to a point beyond that for which they were designed, the friction exceeds the practical limit and the bearing heats. The only thing to do to remedy this difficulty is to reduce the load on the engine.

When an engine is being run under a load that is near or

equal to the maximum for which it is designed, it is wise to keep a set of new brasses on hand, to be put in place when required. This precaution is especially important in a plant where the shutting down of the engine for any great length of time will incur a large loss, and it should be observed especially if it is known that the journals are too small, or the engine is somewhat overloaded.

85. Engine Out of Line.—If an engine is not well lined—that is, if the bearings are not lined up properly—the brasses do not bear fairly upon the journals. This will reduce the area of the wearing surfaces in contact to such an extent that the friction is in excess of the practical limit, which will necessarily cause heating.

If the engine is not greatly out of line, the working condition may be considerably improved by refitting the brasses by filing and scraping down the parts that bear most heavily on the journal.

The crosshead guides of an engine out of line are liable to heat, and they will continue to give trouble until the defect is remedied. The guides may also heat from other causes; for instance, the gibs may be set up too tightly. Of course, if such is the case, they should be slacked off. The danger of the guides heating may be very much lessened by chipping zigzag oil grooves in their wearing surfaces and by attaching to the crosshead, oil wipers made of cotton lamp wicking arranged so as to dip into oil reservoirs at each end of guides if they are horizontal, and at the lower end if they are vertical. These wipers will spread a film of oil over the guides at every stroke of the crosshead that will keep them well lubricated.

86. External Heat.—Bearings may get hot from external heat. This may be the case if the engine is placed too near furnaces or in an atmosphere heated by uncovered steam pipes or other means. The excessive heat of the atmosphere will then expand the brasses until they bind on the journals, which will generate additional heat and cause further expansion of the brasses, resulting in a hot bearing.

If the engine is placed close enough to a furnace to cause heating from that source, a tight partition should be put up between them if possible; this will also prevent dirt and grit from the furnace from getting into the bearings. If steam pipes in the room are bare, they should be covered with some good non-conducting material; and in some cases ventilating fans may be used to advantage. Other remedies depend on the conditions and require the judgment of the engineer.

87. Brasses Too Long.—If the brasses are too long and bear against the collars of the journal when cold, they will surely heat after the engine has been running a short time; it is hardly possible to run bearings entirely cold, they *will* warm up a little and the brasses will be expanded thereby, which will cause them to bear still harder against the collars. This, in turn, will induce greater friction and more expansion of the brasses.

This trouble may be overcome by filing a little off each end of the brasses until they cease to bear against the collars while running. A little side play is a good thing, since it promotes a better distribution of the oil and prevents the journal and brasses from wearing into grooves.

88. Springing of Bedplate.—If the bedplate of an engine is not rigid enough to resist the vibration of the moving parts, or if it is sprung from being set unevenly or by the unstable condition of the foundation, the engine will be thrown out of line either intermittently or permanently, and the bearings will heat; but it will do no good to refit the brasses unless the engine bed is stiffened in some way and leveled up if necessary. The form of the bedplate and foundation must generally suggest the best way to meet this difficulty.

89. Springing or Shifting of Outboard Bearing. The effect of the springing or shifting of the outboard bearing—that is, an outer bearing supported on the foundation away from the engine frame—is similar to the springing of

the engine bed; namely, the bearing will be thrown out of line, with the consequent danger of heating. As the pedestal forming the foot of the bearing is usually adjustable, it is an easy matter to readjust it, after which the holding-down bolts should be screwed down tight. This is one of the few instances where it is permissible for the engineer to use his strength on the wrench. As a rule, a nut or bolt should just be set up solid; with very rare exceptions, a sledge hammer should not be used in driving a wrench, as 3-inch steel bolts have been broken in this way. It is also very bad practice to drive up a nut with a cold chisel and hammer, unless the nut is in a position where it is impossible to turn it with a wrench.

If a pedestal is not stiff enough to resist the forces acting on it and it springs, measures should be taken to stiffen it. The method to be used can only be determined from the conditions, and calls for the exercise of judgment on the part of the engineer.

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